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STRIP MINE RECLAMATION WITH MUNICIPAL SLUDGE

by

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16. ABSTRACT

Stabilized municipal sludge was used on three 4-ha demonstration plots of acidic stripmined land. Liquid digested, dewatered, and sludges were used at variable rates to supply and maintain nutrients for vegetating the plots with a grass-legume mixture. All rates resulted in a lush growth that covered the spoil and persisted for 5 years. No deterioration in vegetative yield or quality was observed or measured. Although trace metal concentration in vegetation increased there was no phytotoxicity discerned. Brief, temporary NO_3N increases in soil water resulted from higher applications, but in general the sludge applications had no significant adverse effect on groundwater quality.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report demonstrates methods of using municipal wastewater sludge to ameliorate and revegetate the acidic spoils left from surface mining of coal.

Francis T. Mayo
Director
Municipal Environmental Research
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ABSTRACT

Treated municipal sludge was used to revegetate three 4-ha demonstration plots in the anthracite and bituminous coal mining regions of Pennsylvania. The three sites selected represented more than 100,000 ha of abandoned, barren bituminous strip mine spoil banks and anthracite refuse banks present in the State.

Various types of sludges (liquid digested, dewatered, and composted) were applied at different application rates to supply the necessary nutrient pool for establishing vegetation and to adhere to State guidelines regarding lifetime applications of trace metals on the land. Following sludge application and incorporation, all sites were seeded with a mixture of grasses and legumes. A monitoring system was installed at each demonstration plot to determine the effects of the sludge applications on (1) the bacteriological and chemical qualities of soil percolate and groundwater, (2) soil chemical properties, and (3) the growth and quality of the vegetative cover.

Data collected over a 5-year period indicate that the sludge applications ameliorated the adverse site conditions and resulted in a quick, complete vegetative cover that has persisted and improved each year. No deterioration in vegetation yield or quality has been observed on any site. Although sludge applications increased some trace metal concentrations in the vegetation, all concentrations were below plant tolerance levels, and no phytotoxicity symptoms were ever observed. Before vegetation was established, the sludge applications caused some sporadic, short-lived increases in nitrate-nitrogen concentrations in soil percolate water. But, in general, the sludge applications had no significant adverse effect on the chemical or bacteriological quality of groundwater.

Study results indicate that stabilized municipal sludges can be used to revegetate mined lands in an environmentally safe manner with no adverse effects on the vegetation, soil, or groundwater quality. The study also shows that at the proper rates, single applications of sludge on a mined site can successfully establish vegetation and sustain it for the 5-year period mandated under the Federal Surface Mining Control and Reclamation Act of 1977.

This report was submitted in fulfillment of Cooperative Agreement No. CR807408010 by the Pennsylvania Department of Environmental Resources and The Pennsylvania State University under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period July 1, 1980, to June 30, 1982, but information in the report spans the period November 1, 1976, to June 30, 1982.

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DEFINITIONS

ANALYTICAL METHODS: Percolate, Groundwater Wells, Lakes

pH

The samples were analyzed for pH by direct reading on a pH meter.

Nitrate-Nitrogen

Samples were analyzed for nitrate-nitrogen using an ion-selective electrode as described by Ellis (1976).

Chloride

An ion-selective electrode was used for the determination of chloride as described by Ellis (1976).

Ammonium Nitrogen

A gas sensing electrode was used for the determination of ammonium nitrogen as described in the EPA Methods of Chemical Analysis of Water and Wastes (1979).

Organic Nitrogen

Organic nitrogen was determined using the selenium digestion procedure described in EPA Methods of Chemical Analysis of Water and Wastes (1979).

Ortho Phosphorus

Ortho phosphorus was determined using blue colorimetric procedure described by Jackson (1958).

Sulfate

Sulfate was determined using the Turbidimetric method described in Standard Methods for the Examination of Water and Wastewater (1980).

Metals

A subsample was acidified at the time of collection and analyzed for dissolved metals as described in EPA Methods of Chemical Analysis of Water and Wastes (1979).

Bacteria

Fecal and total coliforms were monitored using the method described in Standard Methods for the Examination of Water and Wastewater (1980).

Sludge

The same methods used for the percolate samples were employed for the determination of pH, nitrate-nitrogen, ammonium-nitrogen and chloride in the sludge.

Total Phosphorus

Total phosphorus was determined using the vanadium method as described by Jackson (1958).

Metals

The sludge was analyzed for metals using a modification of the hydrochloric nitric acid digestion procedure described in EPA Methods of Chemical Analysis of Water and Wastes (1979), followed by reading on an atomic absorption spectrophotometer.

Mercury

Mercury was determined using the cold vapor method described in EPA Methods of Chemical Analysis of Water and Wastes (1979).

Soil Samples

pH

Soil samples were analyzed for pH by mixing 5 gm of <2 mm soil material and 5 ml of distilled water, allowing the slurry to stand 15 minutes, re-mixing, allowing the slurry to stand 15 minutes more, re-mixing, and reading pH on a Fisher Accument Model 210 pH meter.

Exchangeable

Exchangeable calcium, potassium, sodium, and magnesium were determined on the <2 mm fraction by the alternate ammonium acetate extraction method described by Jackson (1958).

Extractable Cations

Extractable iron, aluminum and manganese were determined by the potassium chloride extraction process described by Jackson (1958).

Soil Phosphorus

Soil phosphorus was determined by a modification of the Bray method ($0.03N-NH_4F$ in 0.025-HCl) described by Jackson (1958).

Kjeldahl Nitrogen

Soil nitrogen was determined using the modified Kjeldahl method described by Jackson (1958).

Total Sulfur

Total sulfur was determined using the high-temperature combustion method described in Standard Methods for the Examination of Water and Wastewater (1980).

Extractable Heavy Metals

Extractable copper, zinc, chromium, cobalt, lead, cadmium, and nickel were determined using the dilute hydrochloric extraction procedure described by Jackson (1958).

Vegetation

Kjeldahl Nitrogen

Kjeldahl nitrogen was determined using the method described by Baker *et al*. (1964).

Plant Phosphorus

Plant phosphorus was determined using the method described by Baker *et al*. (1964).

Metals

Copper, zinc, chromium, lead, cobalt, cadmium, and nickel were digested using the ash procedure in Jackson (1958), prior to analysis by atomic absorption spectrophotography. The remaining elements were digested and analyzed using the method described by Baker *et al*. (1964).

SECTION 1

INTRODUCTION

Millions of acres of barren land disturbed by mining activities exist throughout the United States. Much of this land is a source of acid mine drainage, surface runoff, erosion, and sedimentation, all of which have created serious water pollution and land degradation problems. In the United States, surface mining alone has disturbed 1.76 x 10^6 ha (6,700 miles^2), and half of that land was disturbed specifically by coal mining (Schaller and Sutton, 1978). Each year, coal mining will disturb an additional 40,470 ha,much of which will be in the populated eastern half of the United States. Paone et al. (1978) have projected that the amount of land that will be used by the surface coal mining industry will increase from 25,000 ha in 1977 to 47,000 ha in 1990.

Drastically disturbed lands generally provide a harsh environment for establishing vegetation. Major deterrents to vegetation establishment are usually a lack of nutrients and organic matter, low pH, low water-holding capacity, toxic levels of trace metals, compaction, and poor physical condition of the spoil.

The new Federal Surface Mining Control and Reclamation Act of 1977 has established strict regulations for the revegetation of currently mined land (Federal Register, 1982). In general, the law requires establishment of a diverse, effective and permanent vegetative cover of the seasonal variety native to the affected area of land. Furthermore, the cover must be capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area. The Office of Surface Mining Reclamation and Enforcement (OSM), which was established under the law, has recommended performance standards for meeting the revegetation requirements. These recommendations are as follows:

1. The permanent vegetative cover of the area must be at least equal in extent of cover to the natural vegetation of the area and must achieve productivity levels compatible with the approved postmining land use. Both native and introduced vegetation species may be used.
2. The period of responsibility begins after the last year of augmented seeding, fertilizing, irrigation or other work that ensures revegetation success.
3. In areas of more than 66 cm of annual precipitation, the period of extended responsibility will continue for not less than 5 years. In areas with 66 cm of precipitation or less, the period of

responsibility will continue for not less than 10 years.

4. Normal husbandry practices essential for plant establishment will be permitted during the period of responsibility so long as they can reasonably be expected to continue after bond release.

5. In areas of more than 66 cm of precipitation, the vegetative cover must be equal to the success standard only during the growing season of the last year of the responsibility period (or during the last 2 years if required by the regulatory authority). In areas with less than 66 cm, the vegetative cover must be equal to the success standard for the last 2 years of the responsibility period.

6. The ground cover, productivity, or tree stocking of the revegetated area shall be considered equal to the success standard approved by the regulatory authority when the parameters are fully equivalent with 90 percent statistical confidence.

In addition to these Federal requirements, individual States will be developing their own regulations defining revegetation performance standards as they are granted primacy by OSM.

Also to be followed are the already existing State and Federal guidelines and regulations related to the land application of sludge (U.S. Environmental Protection Agency, 1977, and Pennsylvania Department of Environmental Resources, 1977). Most of these guidelines limit sludge application rates based on nitrogen and other plant nutrient requirements of the vegetation as well as trace metal loadings.

Bastian et al. (1982) have reported that more than 4.2 million dry tons of treated and processed sludge are produced annually. About 42 percent is applied to the land as a soil amendment or fertilizer, and the remainder is incinerated (27%), landfilled (15%), stored in lagoons (12%), or disposed of in the ocean (4%) (Feliciano, 1982).

Considerable research has been conducted during the past decade showing that stabilized municipal sludge from secondary wastewater treatment plants is an excellent soil amendment and fertilizer. But even though a sound technical base exists to support the use of sludge for land reclamation, the public has been reluctant to accept the concept.

To bridge this gap between available technical information and public understanding, a cooperative project was initiated in 1977 to establish several 4-ha plots in the anthracite and bituminous coal-mining regions of Pennsylvania and to demonstrate that sludge can be used for revegetating mined land in an environmentally acceptable manner.

The present study continues the 1977 project. The initial grant from the U.S. Environmental Protection Agency (EPA) was used to establish three 4-ha demonstration plots in the anthracite and bituminous coal mining regions of Pennsylvania (Figure 1). The three sites were representative of abandoned, barren bituminous and anthracite mines. All were treated with various types

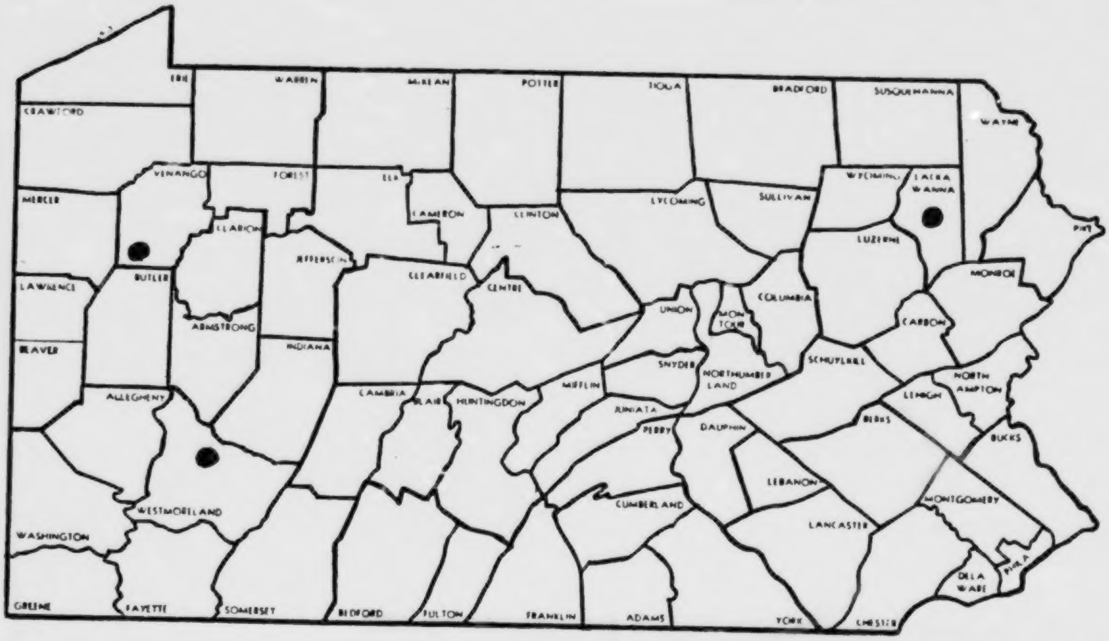
ERIE
WARREN
McKEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
VENANGO
FOREST
ELK
WYOMING
LACKAWANNA
MERCER
CAMERON
CLINTON
LYCOMING
SULLIVAN
CLARION
LUZERNE
PIKE
JEFFERSON
CLEARFIELD
BUTLER
LAWRENCE
CENTRE
MONROE
UNION
COLUMBIA
MONTOUR
ARMSTRONG
CARBON
BEAVER
INDIANA
SNYDER
NORTHUMBERLAND
SCHUYLKILL
NORTHAMPTON
ALLEGHENY
CAMBRIA
BLAIR
HUNTINGDON
MIFFLIN
LEHIGH
JUNIATA
BERKS
PERRY
DAUPHIN
BUCKS
LEBANON
WESTMORELAND
CUMBERLAND
MONTGOMERY
WASHINGTON
LANCASTER
DELAWARE
PHILA
GREENE
FAYETTE
SOMERSET
BEDFORD
FULTON
FRANKLIN
ADAMS
YORK
CHESTER

Figure 1. General location of the demonstration sites in the coal mining regions of Pennsylvania.

of municipal sludges at various application rates and broadcast-seeded with a mixture of grasses and legumes. A monitoring system was installed at each demonstration site to determine the effects of the sludge application on (1) the chemical and bacteriological quality of groundwater and soil percolate water, (2) the chemical properties of the soil, and (3) the quality and growth of the vegetative cover. Data collected during the first 3-year period were reported in the final report of the initial grant. These results, as well as detailed information on each demonstration site, are available in the complete report (NTIS Order No. PB 82-102484), entitled "Revegetating Strip-Mined Land with Municipal Sewage Sludge" (Sopper and Kerr, 1980, 1981).

OBJECTIVES

The purpose of the present project was to continue to collect samples from the existing monitoring system at each demonstration site. The broad objectives were threefold: (1) to demonstrate that municipal sludge could be used in an environmentally acceptable manner to revegetate lands disturbed by mining activities, (2) to reduce erosion and stream siltation, and (3) to reclaim land damaged by mining activities so that it could be returned to agricultural uses.

The Pennsylvania Department of Environmental Resources (PDER) currently requires monitoring for 2 years after land application of sludge. The revegetation regulations developed by the Federal Office of Surface Mining Reclamation and Enforcement require a 5-year period of responsibility for vegetation establishment and regeneration in areas with more than 66 cm of precipitation. The first demonstration plot in Venango County was established in May 1977. This project monitored the plot through five growing seasons (1977-1981). The other two demonstration plots in Westmoreland and Lackawanna Counties were monitored for 2 and 4 years, respectively.

SECTION 2

CONCLUSIONS

The results from these demonstration projects indicate that stabilized municipal sludges can be used to revegetate bituminous strip-mined land and anthracite refuse banks in an environmentally safe manner with no adverse effects on vegetation, soil, or groundwater quality and with little risk to animal or human health. Specific conclusions based on results obtained at each demonstration site are as follows:

VENANGO COUNTY DEMONSTRATION

1. Single applications of dewatered sludge at rates of 90 and 184 dry mt/ha produced a complete vegetative cover of grasses and legumes within 2 months on a bituminous strip-mine spoil bank. Without any further amendment of the soil, the vegetation persisted for a period of 5 years with no deterioration in yield or quality.

2. Application of liquid digested sludge at rates of 103 and 155 m^3/ha (equivalent to 7 and 11 dry mt/ha) produced a similar complete vegetative cover that has also persisted for 5 years without deterioration.

3. Vegetative height growth ranged from 29 to 35 cm during the first growing season. Vegetation height growth continued to increase throughout the five growing seasons (1977-81) following sludge application. In 1981, height growth ranged from 48 to 54 cm.

4. Vegetative dry matter production ranged from 4.8 to 7.7 mt/ha during the first growing season. Dry matter productivity continued to increase throughout the five growing seasons (1977-81) following sludge application. Dry matter production ranged from 19.8 to 32.9 mt/ha in 1981.

5. Foliar concentrations of nutrients, cations, and trace metals in vegetation were higher on sludge-treated areas. Most foliar trace metal concentrations decreased with time over the 5-year period. All foliar trace metal concentrations were below plant tolerance levels, and no phytotoxicity symptoms or nutrient deficiency symptoms were observed.

6. The vegetative cover has steadily improved over the five growing seasons following sludge application. No decrease in yield nor deterioration in quality of vegetation has been observed.

7. The highest application of dewatered sludge (184 mt/ha) slightly increased the concentration of NO_3-N in soil percolate water at the 90-cm depth during the first 3 months following application in 1977. Highest monthly average concentration was 13.0 mg/l. After vegetation establishment, concentrations of NO_3-N decreased well below the allowable maximum for potable water (10 mg/l) and remained there throughout the period 1977-82. Concentrations of NO_3-N in soil percolate water on adjacent untreated areas ranged from 0.5 to 2.8 mg/l over the 5-year period.

8. The highest application of liquid digested sludge (11 mt/ha) significantly increased the concentration of NO_3-N in soil percolate water at the 90-cm depth during the first 2 months following application. Highest monthly average concentration was 33.9 mg/l. This was partially due to the fact that the NO_3-N concentration was much higher (1780 ppm) in the liquid digested sludge than in the dewatered sludge (46 ppm) and was more susceptible to leaching before vegetation establishment. After vegetation establishment, NO_3-N concentrations decreased to levels significantly below 10 mg/l and remained at low levels throughout the 5-year monitoring period (1977-82).

9. Sludge applications did not significantly increase trace metal concentrations in soil percolate water. Only slight increases in concentrations of Zn, Ni, and Co were observed during the first year in the percolate collected from the 184-mt/ha sludge-treated area. Percolate water quality met U.S. Environmental Protection Agency (USEPA) drinking water standards with only a few exceptions. Concentrations of Zn and Ni exceeded the maximum allowable concentration for potable water during the first 3 months (1977) on the 184-mt/ha sludge-treated area. Concentrations of Cr and Pb exceeded the maximum allowable concentration for potable water on both control and sludge-treated areas. During the second, third, and fourth years, only concentrations of Pb exceeded the maximum allowable concentration for potable water on both the control and the areas receiving sludge. During the fifth and sixth years (1981-82) all trace metal concentrations were within the drinking water limits.

10. Fecal coliform colonies were only observed in soil percolate water on one sampling date (August 1, 1980) during the 5-year monitoring period. This occasion was 3 years after sludge application.

11. Sludge applications did not significantly affect the groundwater concentrations of orthophosphate-P, NO_3-N, NH_4-N and organic-N or pH. Average monthly concentrations of NO_3-N were consistently below 10 mg/l during the 5-year period. The only significant effect was a short-lived peak in NO_3-N concentration (to 16.0 mg/l) in the groundwater well influenced by the liquid digested sludge application. This peak occurred during the first month following sludge application and was correlated with the high NO_3-N concentrations found in the soil percolate water samples.

12. Sludge applications did not significantly increase trace metal concentrations in groundwater. Most trace metal concentrations were within the USEPA drinking water standards over the 5-year period. Lead and Cr were the only elements which exceeded the maximum allowable drinking water concentration for both control and sludge-treated areas.

13. No fecal coliforms were found in any groundwater samples collected after sludge application during the period July 1977 through April 1982.

14. The highest sludge application (184 mt/ha) significantly increased the amount of Bray phosphorus in the 0- to 15-cm soil depth. Concentrations remained at high levels throughout the 5-year monitoring period.

15. The highest sludge application (184 mt/ha) did not significantly increase the amount of Kjeldahl nitrogen in the soil during the first 4 months. However, significant increases were noted during the second to the fifth year.

16. The highest sludge application (184 mt/ha) resulted in some increases in trace metal concentrations in the soil. However, these concentrations were extremely low and were within the normal range for soils in the United States. Trace metal concentrations tended to increase with time over the 5-year period. Except for Cu, Zn and Cr, all trace metal concentrations in the 0-15 cm soil depth on the sludge treated plots were similar to that of several prime farmland soil types in Pennsylvania.

17. Sludge application and liming significantly increased soil pH. Treatments increased pH of the 0- to 15-cm soil depth from 3.8 to an average of 6.8 within 4 months. These increased pH levels were maintained throughout the following 5 years.

LACKAWANNA COUNTY DEMONSTRATION

1. Application of dewatered sludge at rates of 80 and 108 dry mt/ha produced a complete vegetative cover of grasses and legumes within 2 months on an anthracite refuse bank and it has persisted for a period of 4 years with no deterioration in yield or quality.

2. Average vegetation height growth during the first year (1978) was 35 and 47 cm for the 80 and 108 mt/ha sludge application rates. Average height growth in 1981 for the same plots were 36 and 38 cm, respectively.

3. Average vegetative dry matter production the first growing season was 4.0 and 3.3 mt/ha for the 80 and 108 mt/ha sludge application rates. Dry matter productivity increased to 14.7 and 17.3 mt/ha by 1981.

4. Foliar concentrations of nutrients, cations, and trace metals in vegetation were increased by the sludge applications. There was little difference between concentrations for the two sludge application rates. In general, foliar concentrations of trace metals decreased during the 4-year period. Trace metal concentrations of Zn, Cr, Pb, Cd, and Ni were higher in grasses on control areas than on the sludge-treated areas. All trace metal concentrations were below plant tolerance levels, and no phytotoxicity or nutrient deficiency symptoms were observed.

5. Sludge applications increased trace metal concentrations in the 0-15 cm soil depth over the 4-year period. These increases were minimal and all trace metal concentrations, except Cr on the 80 mt/ha sludge application, were less than maximum concentrations for trace metals reported for several prime farmland soil types in Pennsylvania.

6. Concentrations of NO_3-N in soil percolate water at the 90-cm depth were not significantly increased by the sludge applications. The highest average monthly concentration recorded during the 4 years following sludge application was 7.6 mg/l.

7. Applications of lime and sludge had no significant effect on soil percolate water pH, which generally remained at levels below 5.0 before and after treatment.

8. Sludge applications did not significantly increase trace metal concentrations in soil percolate water. Trace metal concentrations decreased during the second year and remained at low levels through the fourth year after sludge application. Concentrations of all trace metals except Pb in soil percolate water were below the maximum allowable limits for potable water. Lead concentrations occasionally exceeded the maximum allowable concentration for potable water on both control and sludge treated plots.

9. No fecal coliforms were found in any soil percolate water samples collected after sludge application during the period July 1978 to April 1982.

10. Sludge applications did not significantly affect the groundwater concentrations of orthophosphate-P, NO_3-N, NH_4-N and organic-N or pH. Average monthly concentrations of NO_3-N were consistently below 10 mg/l during the 4 years after sludge application.

11. Sludge applications did not significantly increase trace metal concentrations in groundwater. All trace metal concentrations, except Pb, were below the maximum allowable concentrations for potable water during all 4 years. Lead concentrations occasionally slightly exceeded potable water limits.

12. No fecal coliforms were found in any groundwater samples collected after sludge application during the period July 1978 to April 1982.

WESTMORELAND COUNTY DEMONSTRATION

1. Application of composted sludge at the rate of 134 dry mt/ha during the fall season (September 1979) produced an adequate vegetative cover of winter rye to protect the site from erosion and runoff during the winter season. A complete vegetative cover developed during 1980 following a spring seeding of a mixture of grasses and legumes.

2. The vegetation grew to an average height of 68 cm during the first growing season (1980) following the fall application of sludge. Average height growth remained essentially the same (64 cm) during the second growing season (1981).

3. Average dry matter production during the first growing season (1980) following the fall application of sludge was 11 mt/ha. This increased to 31 mt/ha in 1981.

4. Sludge application significantly increased the amount of Bray phosphorus in the 0-15 cm soil depth during the first year followed by a further sevenfold increase during the second year.

5. Sludge application significantly increased Kjeldahl nitrogen in the 0-15 cm soil depth during the first year; however, it decreased to pre-treatment levels by the end of the second year.

6. Soil pH was only increased slightly at all depths by the lime and sludge applications. The increased pH remained relatively constant during the 2-year period.

7. Sludge application increased trace metal concentrations at the 0-15 cm soil depth after both the first and second year. Most increases were minimal and were within normal ranges for soils in the United States.

8. Sludge application did not significantly effect the soil percolate water concentrations of orthophosphate-P, NO_3-N. NH_4-N, and organic-N or pH. Nitrate-N concentrations were extremely low (<2.0 mg/l) before sludge application and remained at these low levels during the 2-year period following sludge application.

9. Sludge application did not significantly effect trace metals concentrations of soil percolate water during the two years following application. Concentrations of all trace elements, except Pb, were within USEPA drinking water standards. Lead concentrations exceeded these limits on both the control and sludge-treated areas.

10. Sludge applications did not have any significant effect on groundwater quality during the 2-year period following application except for a decrease in pH. Nitrate-N concentration remained below 10 mg/l. Concentrations of all trace metals, except Pb, were below the maximum allowable limit for potable water. Lead concentrations exceeded this

limit on both the control and sludge-treated area.

11. No fecal coliforms were found in any soil percolate samples collected during the 2-year period after sludge application. Fecal coliforms were observed in only one groundwater sample collected one year after sludge application (count was 1 colony per 100 ml).

GENERAL

1. Single applications of stabilized municipal sludges at rates ranging from 7 to 202 dry mt/ha were successful in rapidly revegetating mined land without significant adverse effects on vegetation, soil, soil percolate and groundwater quality.

SECTION 3

RECOMMENDATIONS

1. Continued study is needed to evaluate the longevity of the sludge treatment effects and to determine the optimum application rates needed to achieve permanent revegetation.

2. Study is needed to evaluate the effect of acid precipitation on leaching of trace metals from the sludge after application and from the soil after the sludge has been mineralized and trace metals are released to the soil.

3. Continued study is needed to evaluate the permanence of the vegetation cover established with single sludge applications, particularly, in relation to the proposed regulations under the Surface Mining Control and Reclamation Act of 1977 requiring that the vegetative cover be maintained for a minimum of 5 years and 10 years depending on annual precipitation.

4. Continued study is needed to evaluate the permanence of the sludge treatments on the amelioration of the surface spoil material.

5. Additional studies should be conducted to compare the economics of sludge treatments with conventional methods now being used for the revegetation of strip mined land. In lieu of the new strict revegetation requirements now being developed by the Office of Surface Mining Reclamation and Enforcement, current conventional methods will have to be modified. More seed, lime, and fertilizer will have to be used escalating the cost of reclamation. Thus single applications of municipal sludge might become more cost effective.

6. Study is needed to evaluate the effect of the sludge applications on the re-establishment of the microbiological communities within the surface spoil material.

7. Study is needed to evaluate the effect of the sludge applications on both grass and legume species root system development, including nodulation of legume roots.

8. Study is needed to evaluate the relative population size, community structure, productivity, and health of ground-nesting birds and small mammals on sludge-treated mined lands.

9. Study is needed to determine the relative abundance of invertebrate fauna that serve as a potential food resource for vertebrate animals on sludge-treated mined lands.

10. Study is needed to evaluate the effects of extra high sludge application rates on "worst-case" abandoned mined lands where groundwater pollution is not a limiting factor.

11. Study is needed to determine the effect of the sludge-applied trace metals on crops if the land is used for non-forage crop production after the 5 or 10 year bonding period is over.

SECTION 4

DEMONSTRATION PLOTS

VENANGO COUNTY

This site was representative of bituminous strip mine banks, that have been backfilled and recontoured after mining without soil replacement. Several unsuccessful attempts had been made to revegetate the area using lime, commercial fertilizer, and seed. The surface spoil was compacted, extremely acid (pH 3.8), and devoid of vegetation. A 4-ha demonstration plot was established. The plot was scarified with a chisel plow to loosen the surface spoil material and then treated with agricultural lime (4.5 to 12.3 mt/ha) to raise the spoil pH to 7.0.

Sludge for the project was obtained from three local waste treatment plants. Liquid digested sludge, obtained from the cities of Farrell and Oil City, was transported to the site in tank trucks. Dewatered sludge was obtained from Franklin where the sludge is dewatered by centrifuging, and from Oil City where the sludge is dewatered by spreading on sand drying beds. The dewatered sludge was brought to the site in coal trucks. The 4-ha plot was subdivided into four 1-ha subplots for application of liquid digested sludge at two rates and dewatered sludge at two rates. Liquid digested sludge was applied with a vacuum tank liquid manure spreader at 103 m^3/ha (equivalent to 7 mt/ha) and 155 m^3/ha (equivalent to 11 mt/ha). Dewatered sludge was applied at 90 and 184 mg/ha.

Immediately after sludge application and incorporation, the site was broadcast seeded with a mixture of two grasses and two legumes. The seeding mixture was Kentucky-31 tall fescue (22 kg/ha), Pennlate orchardgrass (22 kg/ha), Penngift crownvetch (11 kg/ha), and Empire Birdsfoot trefoil (11 kg/ha). The site was mulched with straw and hay at the rate of 3.8 mt/ha.

The amounts of trace metals applied at the highest liquid and dewatered sludge application rates are given in Table 1 along with the EPA and Pennsylvania Department of Environmental Resources (PDER) interim guideline recommendations. The amounts of trace metals applied even at the highest sludge application rate were well below the recommended lifetime limits except for copper, which slightly exceeded the Pennsylvania guidelines.

The amounts of nutrients applied by each of the sludge application rates are given in Table 2. Potassium is the only plant nutrient deficient in all sludge application rates. The commercial fertilizer equivalents are also given in Table 2. The highest sludge application rate (184 mt/ha) was equivalent to applying an 11-9-0 commercial chemical fertilizer at 22 mt/ha.

TABLE 1. TRACE METAL LOADINGS (kg/ha) OF THE HIGHEST LIQUID AND DEWATERED SLUDGE APPLICATIONS AT THE VENANGO COUNTY DEMONSTRATION COMPARED WITH EPA AND PDER RECOMMENDATIONS.

Constituent	kg/ha Loading at Sludge Application Rates (mt/ha) 11	184	kg/ha Recommendations EPA[1] (CEC 5-15)	PDER
Cu	21	129	280	112
Zn	21	147	560	224
Cd	0.1	0.6	11	3
Pb	10	55	1,120	112
Ni	1	12	280	22
Cr	16	74	NR[2]	112
Hg	0.01	0.09	NR[2]	0.6

[1] Average CEC of site ranged from 11.6 - 15.2 meq/100g.

[2] No recommendations given by EPA.

TABLE 2. COMMERCIAL FERTILIZER EQUIVALENTS OF THE SLUDGE APPLICATION AT THE VENANGO COUNTY DEMONSTRATION SITE.

Sludge Application Rate mt/ha	Amount, kg/ha	Fertilizer Equivalent (Fertilizer Formula)[1] N, kg/ha(%)	P_2O_5, kg/ha(%)	K_2O, kg/ha(%)
184[1]	22,400	2,388(11)	2,103(9)	21 (0)
90	11,200	1,165(10)	1,026(9)	11 (0)
11	2,240	284(13)	143(6)	6 (0)
7	2,240	187(8)	95(4)	2 (0)

[1] For example, 184 mt sludge/ha is equivalent to 11-9-0 fertilizer at 22,400/ha.

WESTMORELAND COUNTY

This site was also an abandoned bituminous spoil bank and was selected to evaluate a fall application of sludge. All other demonstration sites received early summer sludge applications. This demonstration would allow the evaluation of a fall seeding to establish a vegetative cover and the efficacy of that cover to control the environmental effects of the sludge application. The site had been recontoured without topsoil replacement and was abandoned for approximately 10 years.

Sludge for the project was obtained from the City of Philadelphia Water Pollution Control Plant, which is located approximately 450 km from the site. The plant produces a dewatered centrifuged sludge that is composted with wood chips. The composted sludge is then mixed with equal parts of centrifuged sludge cake to increase the nutrient value of the final product. The total nitrogen content of the composted sludge is approximately 0.6 percent; whereas, the centrifuged sludge cake total nitrogen content is approximately 2.0 percent.

Results of the analyses of the compost-cake mix were used to calculate the amounts of selected nutrients and trace metals applied. The results indicated that at the selected application rate of 134 mt/ha, the compost-cake mix supplied 968 kg nitrogen/ha, 1,816 kg phosphate/ha, and 215 kg potash/ha to the area. This would be equivalent to applying a 10-18-1 commercial fertilizer at 10 mt/ha. The value of sludge as a substitute for commercial fertilizer is obvious.

A comparison of the application rate with the EPA and PDER recommendations for maximum trace metal loadings on the land indicates that the recommended limits were essentially met with the sludge application rate of 134 mt/ha (Table 3). At an application rate of 134 mt/ha, the trace metal content of the sludge is well below the limits recommended by the EPA and, with the exception of zinc, meets all PDER guidelines.

Pretreatment surface soil samples were collected and analylzed for pH and buffer pH to determine the liming requirements. Results indicated that the average soil pH was 4.3. In September, 13 mt agricultural lime/ha were applied to adjust the soil pH to 7.0.

In September, coal trucks brought the compost-cake mix from Philadelphia to the site on a return trip after delivering coal. The sludge was loaded into manure spreaders and spread on the site. Immediately after the spreading, the area was chisel plowed to incorporate the sludge into the surface 10 cm of spoil material.

After incorporating the sludge, the area was broadcast seeded with a mixture of Kentucky 31 Tall Fescue (11 kg/ha), Birdsfoot trefoil (6 kg/ha), and winter rye (63 kg/ha). Completion of seeding by October 1, 1979, allowed approximately 6 to 8 weeks for vegetation growth to become winter hardy. The following spring the remaining portion of the seeding mixture was broadcast. The spring seeding mixture was orchardgrass (11 kg/ha), and birdsfoot trefoil (6 kg/ha).

TABLE 3. TRACE METAL LOADINGS (kg/ha) AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT COMPARED WITH EPA AND PDER RECOMMENDATIONS.

Constituent	kg/ha Loading at Sludge Application of 134 mt/ha	kg/ha Recommendations EPA (CEC >15)	PDER
Cd	0.2	22	3
Cu	76	560	112
Cr	42	NR[2]	112
Pb	59	2,240	112
Hg	0.06	NR[2]	0.6
Ni	13	560	22
Zn	245	1,120	224

[1] Average CEC of site from 16.7 to 19.0 meq/100g.
[2] No recommendation given by EPA.

LACKAWANNA COUNTY

This site consisted of a 24-ha anthracite refuse bank, devoid of vegetation, in Scranton, Pennsylvania. It was severely eroded and a constant eyesore. In April 1978, a 4-ha area was recontoured for the demonstration plot.

A chisel plow was used to loosen the surface refuse material because of the compaction caused by the leveling process. Analyses of surface refuse samples indicated a pH of 3.6; therefore 11 mt lime/ha was applied to the area.

Dewatered, vacuum-filtered, sludge was obtained from the Scranton waste water treatment plant. The sludge was applied at 80 and 108 mt/ha rates with manure spreaders and incorporated. The area was broadcast seeded with the same mixture of grasses and legumes as in the Venango County demonstration. The area was then mulched with hay and straw at the rate of 3.4 mt/ha.

The amounts of trace metals applied by the two sludge application rates are given in Table 4 along with the EPA and PDER guideline recommendations. Both sludge application rates were well below all recommendations for maximum trace metal loadings. The highest sludge application rate applied 1,691 kg nitrogen, 1044 kg phosphate, and 169 kg potash/ha. This would be equivalent to applying a 15-9-2 commercial fertilizer at 11 mt/ha.

TABLE 4. TRACE METAL LOADINGS (kg/ha) ON THE UNBURNED ANTHRACITE REFUSE SITE IN LACKAWANNA COUNTY COMPARED WITH EPA AND PDER RECOMMENDATIONS.

Constituent	kg/ha Loading at Sludge Application Rate (mt/ha)		kg/ha Recommendations	
	80	108	EPA (CEC 5-15)[1]	PDER
Cu	67	92	280	112
Zn	64	86	560	224
Cd	1.2	1.7	11	3
Pb	49	67	1,120	112
Ni	4.4	5.9	280	22
Cr	16	21	NR[2]	112
Hg	0.1	0.2	NR[2]	0.6

[1] Average CEC of site ranged from 11.1 to 11.6 meq/100g.

[2] No recommendations given by EPA.

SECTION 5

MONITORING SYSTEM

A complete monitoring system was installed at each demonstration plot to evaluate the effects of the sludge applications on water quality, vegetation, and soil. The monitoring program included drilling groundwater wells, installing suction lysimeters, and collecting and analyzing soil and vegetation samples. A detailed description of the monitoring system is as follows:

GROUNDWATER QUALITY

Groundwater wells were drilled at each demonstration site to sample groundwater quality. One well was located upslope to sample background water quality and two wells were located down-gradient of the sludge-treated plots to sample the effects of the sludge application on groundwater quality. Groundwater samples were collected from the wells with a portable trailer-mounted submersible pump and a Kemmerer water sampler. In order to obtain benchmark data on water quality, groundwater samples were collected from all wells prior to sludge application. After sludge application, groundwater samples were collected bi-weekly for the first two months and monthly thereafter. Samples were analyzed for pH, ortho-P, NO_3-N, NH_4-N, Organic N, Ca, Mg, Na, K, Cu, Zn, Co, Cr, Ni, Pb, Cd, Fe, Mn, Al, and total and fecal coliforms.

SOIL PERCOLATE WATER QUALITY

Suction lysimeters were installed at the 90 cm soil depth for the collection of percolate water samples. Four to 18 pits were excavated on each 10-acre site for the installation of the lysimeters. Three to four additional pits were excavated adjacent to the sludge-treated areas to obtain control percolate water samples. Two lysimeters were installed in each pit, one specifically for the collection of percolate water for bacterial analyses (total and fecal coliform) and the other for routine water quality analyses. Samples were collected bi-weekly for the first two months and then monthly thereafter. Water samples were also collected prior to sludge application to obtain background data on leachate water quality. Samples were analyzed for the same constituents as the groundwater samples.

SOIL

Soil samples were collected from all pits excavated for the installation of the suction lysimeters. Soil samples were collected at the 0-15, 15-30, 30-60, and 60-90 cm depth. These samples were analyzed for Kjeldahl nitrogen, Bray phosphorus, pH, Ca, Mg, Na, K, Cu, Zn, Co, Ni, Cr, Pb, Cd, Fe, Mn, Al, and total sulfur. Soil samples were taken at one year intervals to determine the effect of the sludge application on the soil chemical status and to evaluate the fate of the heavy metals.

VEGETATION

At the end of each growing season vegetation growth responses were determined by measurements of percentage areal cover, height growth, and dry matter production. One tenth square meter samples of the vegetative cover were clipped and oven-dried to determine dry matter production in kg/ha. Individual samples of the two grasses (K-31 tall fescue and orchardgrass) and two legumes (crownvetch and birdsfoot trefoil) seeded on each site were collected for foliar analyses. Plant samples were analysed for nitrogen, phosphorus, K, Ca, Mg, Na, Cu, Zn, Co, Ni, Cr, Pb, Cd, Fe, Mn and Al.

SECTION 6

RESULTS

VENANGO COUNTY

Soil

In 1977 soil pits were excavated in each sludge-treated plot and in an adjacent control area. Soil samples were collected at the 0-15, 15-30, 30-60, and 60-90 cm depth for chemical analyses. In 1978, 1979, and 1981 soils at various depths were again collected and analyzed (Tables 5, 6, and Appendix Table A-1). Results of the pre- and post-treatment soil analyses for Kjeldahl nitrogen, Bray phosphorus, K, Ca, and Mg are given in Table 5 for the highest sludge application rate. Results of post-treatment analyses for these constituents for all plots are given in Appendix Table A-1.

The amount of Bray phosphorus in the 0-15 cm soil depth was significantly increased initially by the 184 mt/ha sludge application and remained at a high level through the fifth year. No significant change in Kjeldahl nitrogen was observed during the first four months; however, significant increases were noted during the second to the fifth year.

In general, the sludge application (and lime application) increased the concentrations of calcium and potassium and decreased the concentration of magnesium.

It is not possible to make a direct comparison between the data from the control and sludge plots because of the inherent variability in the soil profile of such a disturbed site and the fact that the pre-treatment and post-treatment samples were not collected from the same pit. Thus, one can only interpret the data in terms of general trends.

Results of the pre- and post-treatment soil analyses for extractable trace metals for the limed plot which received the highest sludge application rate (184 mt/ha) are given in Table 6. Results of soil analyses for all plots are given in Appendix Table A-2. Extractable trace metal concentrations in the 0-15 cm soil depth generally increased over the 5-year period. The increased trace metal concentrations all fall within the normal range for total metal concentrations for soils in the United States as reported by Allaway (1968).

For additional comparison, the extractable trace metal concentration in the 0-15 cm soil depth of several prime farmland soil types in Somerset County, Pennsylvania are given in Table 7. Three composite grab samples were

TABLE 5. CHANGES IN CONCENTRATIONS OF KJELDAHL NITROGEN, BRAY PHOSPHORUS, AND EXCHANGEABLE CATIONS FROM SOILS COLLECTED AT THE 0-15 CM DEPTH FOLLOWING SLUDGE APPLICATION AT 184 MT/HA AT THE VENANGO COUNTY DEMONSTRATION PROJECT.

Sampling Date	Kjeldahl Nitrogen	Bray Phosphorus	K	Ca	Mg
	%		µg/g		
May 1977[1]	0.04	2.00	12	541	452
Sept 1977	0.05	11.17	19	1222	32
1978	0.09	9.00	23	2600	40
1979	0.16	38.17	46	3873	53
1981	0.34	179.25	45	1298	99

[1] May 1977 values represent pretreatment conditions.

TABLE 6. CHANGES IN CONCENTRATIONS OF SOIL EXTRACTABLE TRACE METALS AT THE 0-15 CM DEPTH FOLLOWING SLUDGE APPLICATION AT 184 MT/HA AT THE VENANGO COUNTY DEMONSTRATION PROJECT.

Sampling Date	Cu	Zn	Cr	Pb	Co	Cd	Ni
				µg/g			
May 1977[1]	2.5	2.9	0.2	0.5	0.7	0.02	1.1
Sept 1977	10.8	7.7	0.4	3.5	1.3	0.04	0.9
1978	8.8	7.7	0.2	2.3	1.2	0.02	1.2
1979	58.7	56.9	1.7	13.0	1.2	0.27	1.5
1981	87.3	74.6	3.5	22.7	1.6	0.95	2.8
Normal Range in Soils (Allaway, 1968)	2-100	10-300	5-3000	2-200	1-40	0.01-7.00	5-500

[1] May 1977 values represent pretreatment conditions.

TABLE 7. EXTRACTABLE TRACE METAL CONCENTRATIONS OF SEVERAL PRIME FARMLAND SOIL TYPES IN PENNSYLVANIA.[1]

Soil Type	Cu	Zn	Cr	Pb	Co	Cd	Ni	Sample No.
	---------------------µg/g---------------------							
Monongahela silt loam	6.25	6.60	0.10	5.45	0.65	0.225	1.05	1
	5.55	6.05	0.15	6.70	0.60	0.245	1.10	2
	5.90	4.25	0.10	6.15	0.75	0.239	1.15	3
Albrights silt loam	0.55	2.85	0.20	1.95	0.80	0.275	0.75	1
	0.75	2.55	0.15	2.05	0.55	0.245	0.85	2
	0.85	2.40	0.15	1.75	0.80	0.260	0.95	3
Pope fine sandy loam	1.65	7.40	0.00	2.90	0.30	0.250	2.80	1
	1.85	10.20	0.00	2.60	0.30	0.290	3.05	2
	2.00	8.70	0.00	2.70	0.50	0.275	2.95	3
Rayne-Gilpin channery silt loam	1.00	11.45	0.15	1.65	0.55	0.250	0.90	1
	4.35	11.15	0.20	0.65	0.70	0.280	1.20	2
	2.90	13.65	0.20	1.60	0.95	0.300	1.35	3
Leck Kill channery loam	0.55	2.45	0.15	0.95	0.85	0.210	0.70	1
	0.20	2.55	0.10	0.80	0.65	0.225	0.90	2
	0.45	2.90	0.10	0.80	0.75	0.235	1.00	3
Hazleton channery loam	4.20	2.80	0.05	1.80	0.60	0.170	0.35	1
	3.35	2.75	0.10	1.30	0.75	0.190	0.45	2
	3.70	2.30	0.05	1.80	0.75	0.195	0.35	3
Average	2.56	5.72	0.11	2.42	0.65	0.242	1.21	
	0.20-6.25	2.30-13.65	0.00-0.20	0.65-6.70	0.30-0.95	0.170-0.290	0.35-3.05	

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[1] Samples collected in September 1981. Most fields were in corn production. Samples represent the 0-15 cm soil depth.

collected from each soil type. Copper and Cr concentrations on the sludge-treated plot greatly exceeded the maximum values for the prime farmland soil types. Concentrations of other trace metals were increased from zero to sixfold over the maximum concentrations found in the prime farmland soil types.

Effects of sludge applications on the concentrations of extractable iron, aluminum, and manganese are given in Appendix Table A-3. Most significant changes occurred at the 0-15 cm depth. Results for the 0-15 cm soil depth for the highest sludge application (184 mt/ha) are given in Table 8. Concentrations of iron, aluminum, and manganese all decreased significantly over time following the sludge application.

The effects of the highest liquid application rate and both dewatered sludge application rates on soil pH are shown in Table 9. After four months, soil pH at all depths was increased by all sludge application rates. Even though the liquid application rate was low, it appears that it initially had a greater effect on soil pH, particularly at the greater depths. This was probably due to the fact that the liquid sludge percolated to greater soil depths. However, eighteen months after the sludge application, the soil pH dropped slightly. However, after 30 months the soil pH at the 0-15 and 15-30 cm depths were again at the initial high level. At the higher sludge application rate, 184 mt/ha, the soil pH at both the 0-15 and 15-30 cm depth continued to increase over the 30 month period to values of 7.3 and 5.1, respectively, by October 1979. Similar results were also observed for the 90 mt/ha sludge application. In the fifth year, there was an unexplained decrease in pH at both soil depths on the 184 mt/ha sludge plot. To verify this sudden drop in pH, soil samples at the 0-15 cm depth were again collected in July 1982. Results of these analyses indicated that average soil pH was 6.1.

Vegetation

Vegetation growth responses were evaluated at the end of each growing season. Measurements of vegetation height were taken along transect lines in each treatment area. To determine dry matter production, twenty, 0.1-square meter samples of the vegetative cover were clipped in each treatment area. The results of these measurements are given in Table 10. All sludge-treated areas had a complete cover of vegetation by August 1977, three months after sludge application. The first year average height ranged from 29 to 35 cm, with the greatest growth being produced with the 184 mt/ha sludge application. Vegetation height continued to increase over the five growing seasons for sludge applications. The greatest dry matter production occurred with the 7 and 11 mt/ha liquid digested sludge application rates. These areas had received applications of lime and fertilizer prior to sludge application and had a sparse vegetative cover.

Dry matter production has significantly increased each year for all sludge application rates. Dry matter production as reported here includes all organic matter above ground within the 0.1 m^2 sample plot (green crop and organic litter accumulation). No crops were harvested.

TABLE 8. CHANGES IN CONCENTRATIONS OF SOIL EXTRACTABLE Fe, Al, and Mn AT THE 0-15 CM DEPTH FOLLOWING SLUDGE APPLICATION AT 184 MT/HA AT THE VENANGO COUNTY DEMONSTRATION PROJECT.

Sampling Date	Fe	Al	Mn
	µg/g		
May 1977[1]	40.3	186.3	4.7
Sept 1977	12.6	14.4	3.3
1978	18.7	7.3	4.0
1979	15.8	2.9	4.6
1981	16.2	77.8	27.3

[1] May 1977 values represent pretreatment conditions.

TABLE 9. CHANGES IN SOIL pH FOLLOWING SLUDGE APPLICATIONS AT THE VENANGO COUNTY DEMONSTRATION PROJECT.

Sludge Application	Depth	Soil pH May 1977[1]	Sept 1977	Nov 1978	Oct 1979	May 1981
mt/ha	cm					
11-Lime	0-15	3.8	7.8	5.7	7.3	8.0
	15-30	3.8	6.7	4.5	6.1	3.6
90-Lime	0-15	3.8	6.6	6.6	7.7	7.1
	15-30	3.8	6.6	6.6	6.3	3.7
184-Lime	0-15	3.8	6.2	6.7	7.3	5.8
	15-30	3.8	4.2	4.6	5.1	3.4

[1] May 1977 values represent pretreatment conditions.

Table 10. AVERAGE VEGETATION HEIGHT GROWTH AND DRY MATTER PRODUCTION AT THE VENANGO COUNTY DEMONSTRATION PROJECT

Sludge Treatment	Height				
	1977	1978	1979	1980	1981
mt/ha	cm				
7	29	37	52	55	52
11-Lime	32	30	43	48	48
90-Lime	34	41	41	49	52
184-Lime	35	52	44	58	54
	Dry Matter Production				
	mt/ha				
7	6.3	9.5	18.5	34.4	32.9
11-Lime	7.7	8.7	17.1	26.7	22.8
90-Lime	4.8	7.4	14.3	26.1	19.8
184-Lime	6.0	9.3	11.3	31.2	22.6

During the first two growing seasons the two grass species were the dominant vegetation type on all sludge treated plots. By the third growing season (1979) the two legume species were well developed and had become the predominant vegetative cover on the plots treated with liquid digested sludge (95-100 percent legume cover) and the limed dewatered sludge treated plots (85 percent legume cover). The unlimed dewatered sludge treated plots were still vegetated primarily by the two grass species with only a few sparse patches of legumes (less than 10% legume cover).

In general, the vegetative cover has improved over the five growing seasons following sludge application. No deterioration in vegetation quality or yield has been observed. The sequence of vegetation development is shown in Figures 2, 3, and 4.

At the end of each growing season individual samples of the two grass and two legume species were collected from each sludge-treated area for foliar analyses. A few residual plants of tall fescue, orchardgrass, and birdsfoot

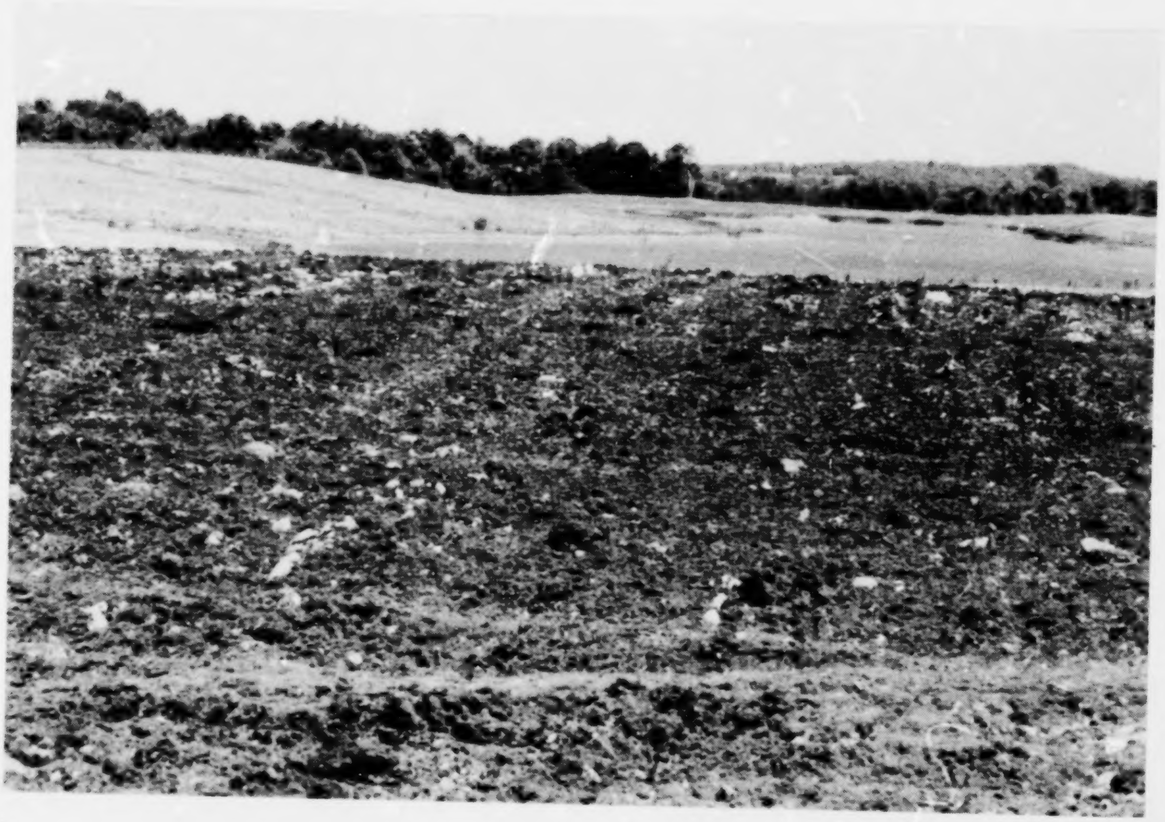

Figure 2(A). Application of 184 mt/ha of dewatered sludge prior to incorporation on the Venango County Demonstration plot.

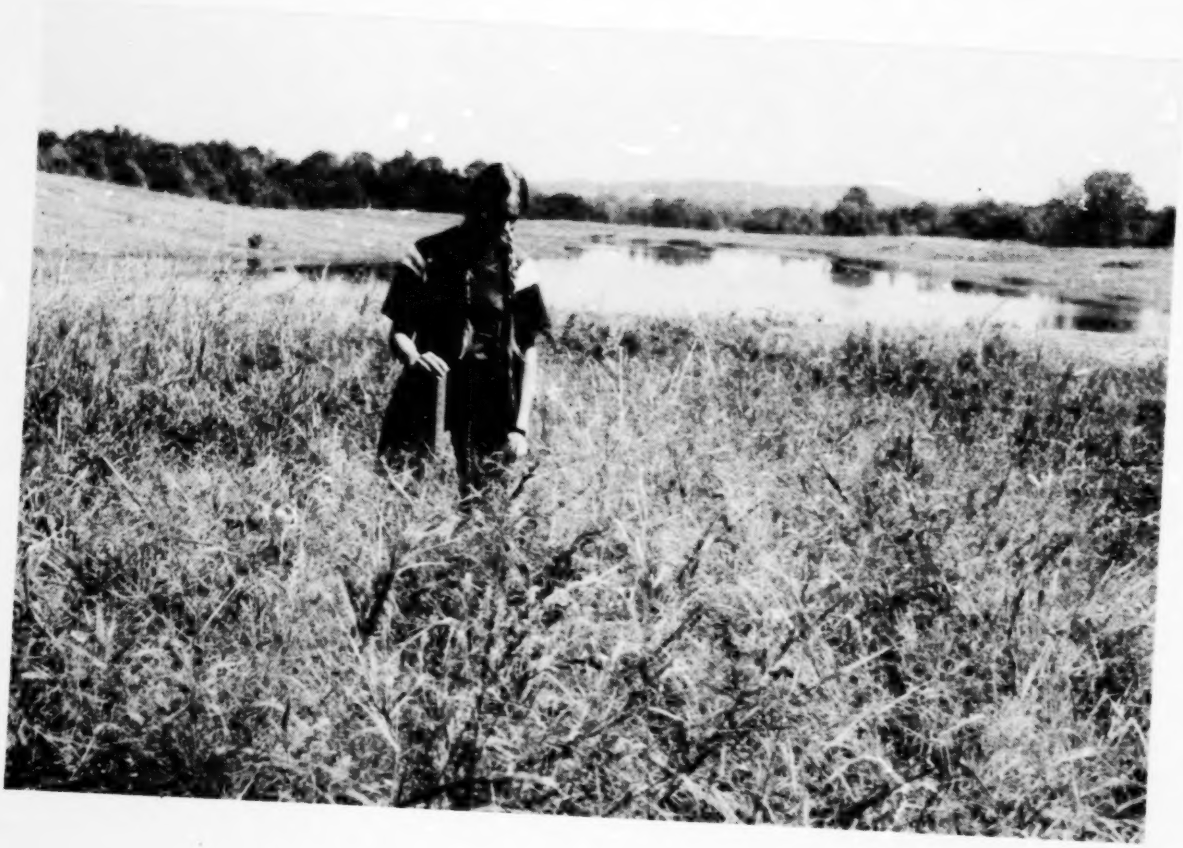

Figure 2(B). Lush dense vegetative cover three months after sludge application on Venango County demonstration plot.

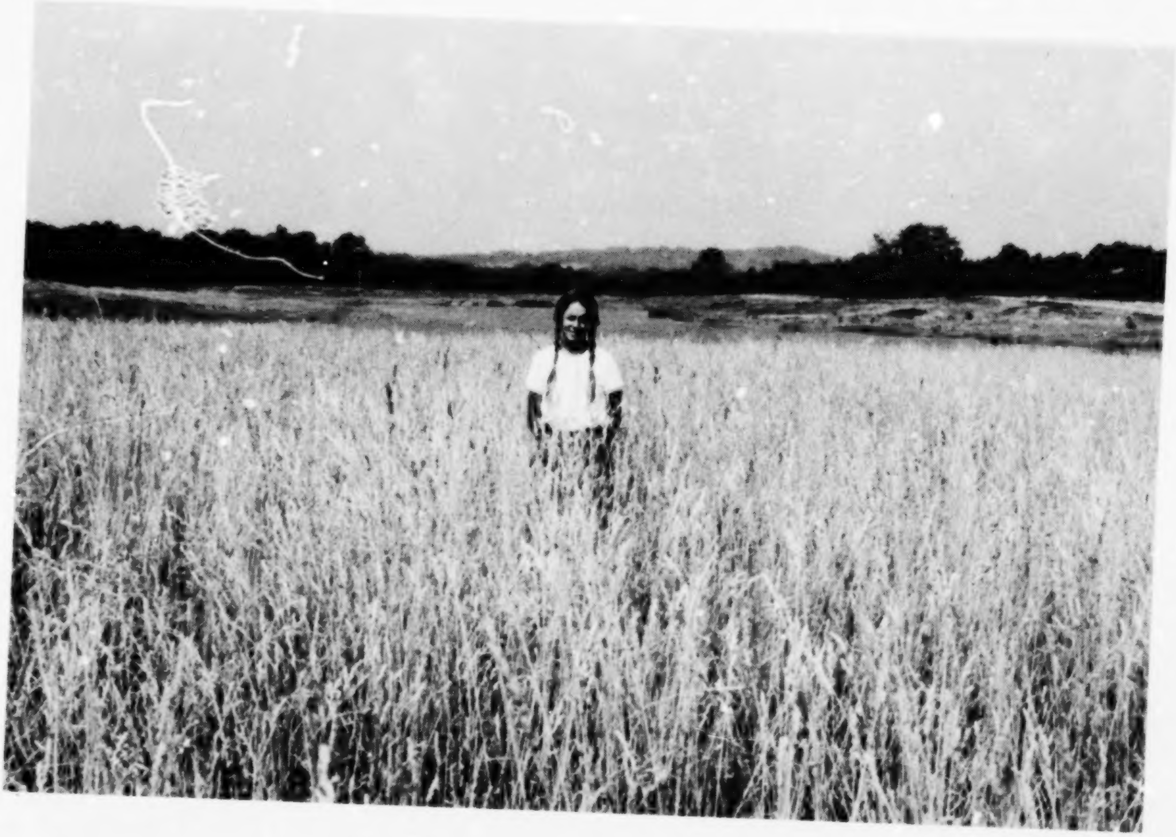

Figure 3(A). Vegetation cover during the second year after sludge application on the Venango County demonstration plot.

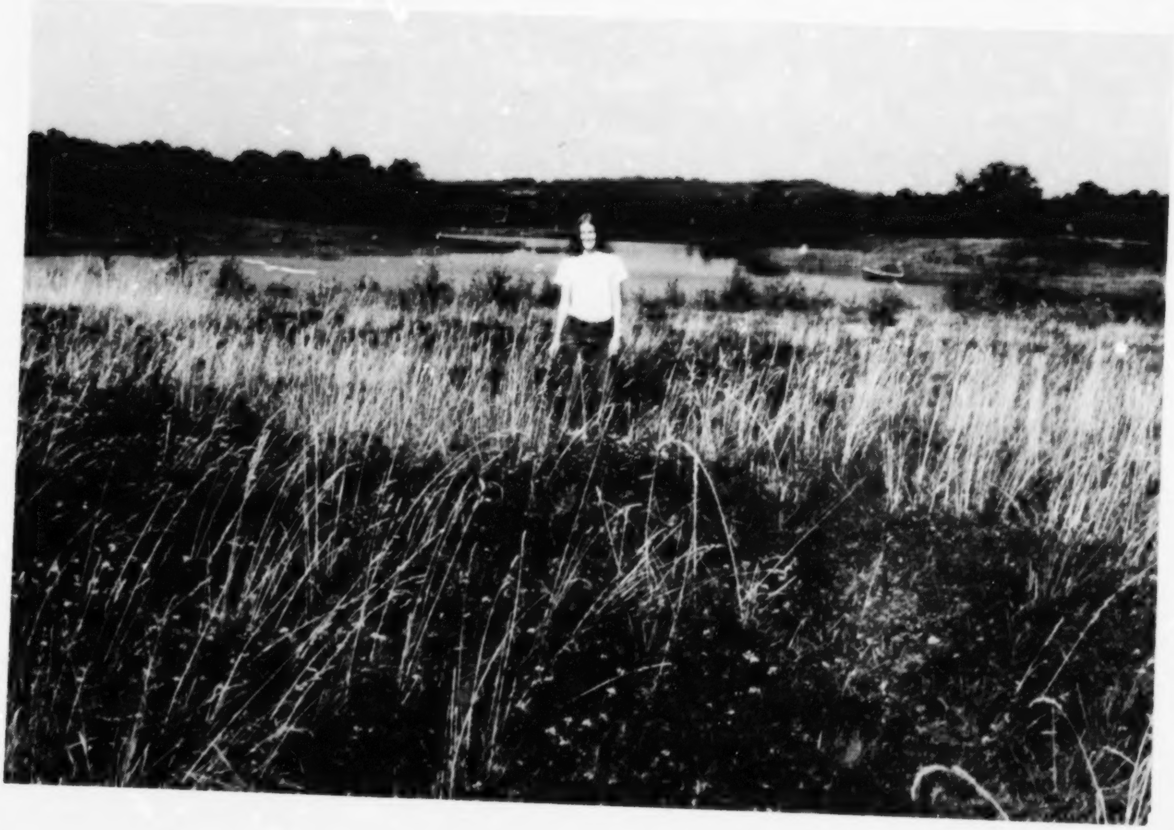

Figure 3(B). Vegetation cover during the fifth year after sludge application on the Venango County demonstration plot.

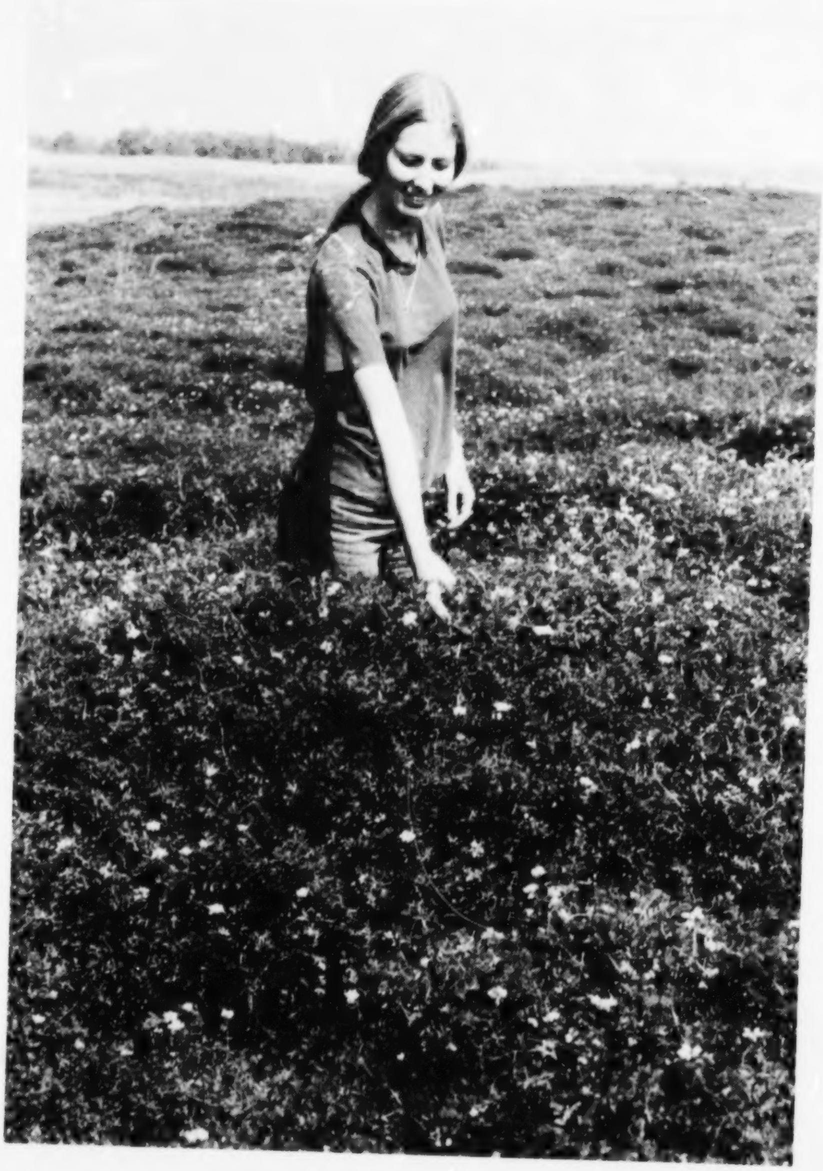

Figure 4. Close-up view of the vegetative cover during the fifth year after sludge application. The initial cover composed primarily of the grass species has now been completely replaced by the dominant legume species.

trefoil from previous reclamation attempts were growing on the surrounding control area. Samples from these plants were also collected for comparison. Results of these analyses for each sludge application rate are given in Appendix, Tables A-4 to A-9. For discussion purposes the analyses for tall fescue and birdsfoot trefoil on the highest sludge-treated plot is given in Table 11 and 12. Species differences are obvious in that, in general on the sludge treated plot, the legume had higher concentrations of nitrogen, calcium, and boron and the grass had higher concentrations of phosphorus, potassium, magnesium, manganese, iron, and aluminum (Table 11). For trace metals on the sludge-treated plot, concentrations were higher in the legume for all elements except cobalt and cadmium. For many of the constituents, higher foliar concentrations appeared to be associated with higher sludge application rates.

Results of the foliar analyses for trace metals indicated that many concentrations were higher on the control area than on any of the sludge-treated areas. This was probably due to soil pH. Surface soil pH (0-15 cm depth) on the control area was 3.8, whereas, on the sludge-treated areas, it ranged from 5.7 to 7.8. In general, foliar concentrations of trace metals in both the grass and legume species decreased over time. Although sludge applications did increase trace metal concentrations in the vegetation foliage, these increases were minimal and well below the suggested tolerance levels and no phytotoxicity symptoms were observed on any demonstration plots (Council for Agricultural Science and Technology, 1976, and Melsted, 1973).

Soil Percolate Water Quality

Results of the analyses of soil percolate water for selected chemical constituents for the highest applications of both the liquid and dewatered sludge plots as well as the control plot are given in Tables 13, 14, and 15. Results of the analyses for all plots are given in Appendix, Tables A-10 to A-12. Average monthly concentrations of NO_3-N in the percolate by October of the first year (1977) after development of a complete vegetative cover, on the plots treated with the highest applications of liquid and dewatered sludge were well below the allowable maximum for potable water (10 mg/l). Concentrations of NO_3-N in the percolate remained below 10 mg/l throughout 1978, 1979, 1980, 1981, and up to April 1982. Highest concentration recorded in 1980-1982 was 3.0 mg/l.

The average concentrations of NO_3-N in percolate water samples collected on the plots treated with the highest application of dewatered sludge from 1977 to April 1982 are plotted in Figure 5. The greatest nitrate leaching occurred during the period of vegetation establishment (Summer 1977). Once vegetation was established, the large uptake of NO_3-N by the growing vegetative cover resulted in a rapid decrease in the amount of NO_3-N available for leaching. The highest concentration recorded for any single sampling date was 13.0 mg/l. No NO_3-N value exceeded 1.2 mg/l on the 184-L plot after October, 1977.

The dewatered sludge applications did not have any significant effect on percolate pH during the 5 years following application. The pH ranged from 3.2 to 4.1.

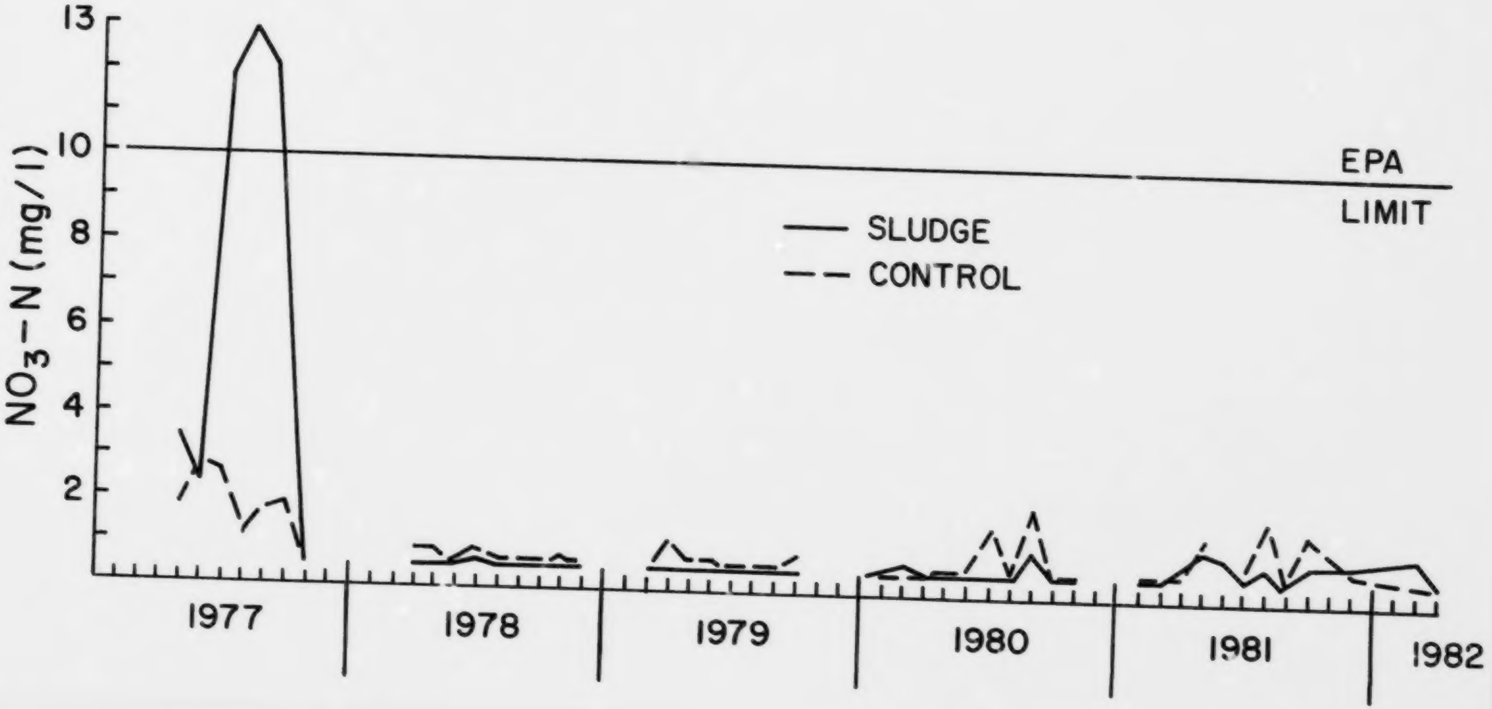

Figure 5. Nitrate-nitrogen concentration in soil percolate water on the area treated with 184 mt/ha of dewatered sludge on the Venango County demonstration plot.

TABLE 11. MEAN FOLIAR CONCENTRATIONS OF SELECTED CONSTITUENTS IN SAMPLES COLLECTED FROM THE CONTROL AND HIGHEST SLUDGE APPLICATION PLOT AT THE VENANGO COUNTY DEMONSTRATION PROJECT.

Sludge Application	Year	N	P	K	Ca	Mg	Mn	Fe	B	Al
mt/ha		- - - - - - - -	- - - -	%	- - - -	- - - - - - - -	- - - -	-µg/g-	- - -	
					Tall Fescue					
0	1977	1.08	0.16	1.35	0.44	0.20	242	626	17	1000
	1978	2.73	0.23	1.95	0.93	0.31	63	553	10	213
	1979	1.01	0.18	1.68	0.40	0.26	209	185	8	123
	1980	0.99	0.16	1.18	0.29	0.18	145	335	6	210
	1981	0.95	0.15	1.28	0.46	0.24	165	138	7	135
184-L	1977	2.32	0.37	3.39	0.62	0.28	243	124	16	40
	1978	2.66	0.32	2.67	1.48	0.51	453	618	32	634
	1979	1.17	0.41	2.34	0.54	0.31	214	51	9	45
	1980	1.08	0.34	1.22	0.49	0.22	268	162	8	97
	1981	2.34	0.33	2.37	0.63	0.33	165	70	7	30
					Birdsfoot Trefoil					
0	1978	1.03	0.24	1.93	0.61	0.26	914	739	13	577
	1979	2.59	0.14	1.74	1.82	0.40	150	113	41	36
	1980	2.11	0.17	1.92	1.02	0.23	94	105	26	49
	1981	3.32	0.17	1.89	1.52	0.29	113	95	34	35
184-L	1977	3.64	0.27	1.46	1.99	0.28	165	93	54	50
	1978	1.27	0.36	2.30	0.59	0.25	527	158	9	106
	1979	3.57	0.25	1.56	1.54	0.20	127	98	36	29
	1980	2.93	0.25	1.62	1.27	0.18	79	97	34	42
	1981	4.03	0.26	1.69	1.14	0.23	119	89	27	27

TABLE 12. MEAN FOLIAR CONCENTRATIONS OF TRACE METALS IN SAMPLES COLLECTED FROM THE CONTROL AND HIGHEST SLUDGE APPLICATION PLOT AT THE VENANGO COUNTY DEMONSTRATION PROJECT

Sludge Application	Year	Cu	Zn	Cr	Pb	Co	Ni	Cd
mt/ha		µg/g						
				Tall Fescue				
0	1977	10.2	23.2	0.9	10.9	1.5	3.1	0.52
	1978	5.7	24.9	0.7	8.8	1.8	4.8	0.27
	1979	3.3	9.4	11.2	1.8	0.6	18.3	0.06
	1980	3.5	17.2	0.7	7.6	1.6	4.6	0.32
	1981	6.6	10.0	<0.1	3.2	<0.1	<0.1	0.27
184-L	1977	9.4	48.4	0.8	4.5	1.5	9.8	0.20
	1978	8.6	44.4	0.8	4.5	1.6	3.7	0.41
	1979	9.2	72.5	0.5	1.8	0.6	2.5	0.08
	1980	3.5	41.9	1.1	3.8	1.8	7.3	0.73
	1981	12.7	34.8	<0.1	1.9	1.0	0.7	0.50
				Birdsfoot Trefoil				
0	1978	7.7	32.2	0.3	8.6	2.6	7.4	0.14
	1979	8.4	38.0	8.5	2.6	0.6	21.4	0.10
	1980	6.9	32.7	0.6	3.8	2.3	8.7	0.13
	1981	9.3	27.0	<0.1	5.5	1.3	7.7	0.50
184-L	1977	13.9	95.9	1.0	7.4	2.1	6.3	0.43
	1978	7.7	30.4	0.3	8.5	3.0	4.8	0.07
	1979	9.2	41.5	1.7	1.8	0.3	6.3	0.04
	1980	8.2	42.3	1.9	4.5	1.4	6.5	0.08
	1981	11.6	40.9	<0.1	1.5	0.9	3.3	0.37
Suggested Tolerance Levels *,+		150	300	2	10	5	50	3

* Melsted (1973)

+ Council for Agricultural Science and Technology (1976)

TABLE 13. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1980.

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - - - - -	- - - - - mg/l	- - - - - - -		
0	Jan	0.008	<0.5	0.57	0.35	4.1
	March	0.006	<0.5	0.48	0.09	4.3
	April	0.008	<0.5	0.50	0.31	4.1
	May	0.009	<0.5	0.66	0.23	4.4
	June	0.009	<0.5	0.80	0.19	3.9
	July	0.003	1.7	0.91	0.18	4.0
	Aug	0.018	<0.5	0.72	0.08	4.1
	Sept	0.036	2.2	0.29	2.67	2.7
	Oct	0.017	<0.5	0.91	<0.05	2.8
	Nov	0.019	<0.5	0.16	0.06	3.8
11-L	Jan	0.009	<0.5	0.20	0.24	4.0
	March	0.012	<0.5	0.26	0.28	3.8
	April	0.017	<0.5	0.21	0.37	4.0
	May	0.018	<0.5	0.30	0.15	3.9
	June	0.024	0.8	0.32	0.23	3.9
	July	0.007	<0.5	0.61	0.35	4.0
	Aug	0.017	<0.5	0.29	0.48	3.9
	Sept	0.026	2.0	1.24	0.28	3.8
	Oct	0.089	1.7	0.67	0.14	4.3
	Nov	0.020	0.7	0.18	0.04	3.9
184-L	Jan	0.010	<0.5	0.07	0.23	3.9
	March	0.015	0.7	0.10	0.08	4.0
	April	0.015	<0.5	0.12	0.24	4.0
	May	0.017	<0.5	0.06	0.20	3.9
	June	0.017	<0.5	0.12	0.17	3.8
	July	0.008	<0.5	0.10	0.08	3.5
	Aug	0.023	<0.5	0.12	0.13	4.0
	Sept	0.033	1.0	0.15	0.08	3.5
	Oct	0.071	<0.5	0.14	<0.05	3.7
	Nov	0.023	<0.5	0.06	<0.05	3.9

TABLE 14. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1981.

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - - - mg/l - - - - - - - - - -				
0	Feb	.001	0.5	0.17	0.08	7.7
	March	.009	0.5	0.49	0.10	4.3
	April	.013	0.5	0.56	0.12	4.2
	May	.006	1.5	0.54	0.19	4.1
	June	.053	18.3[1]	0.67	0.48	4.1
	July	.041	0.8	0.88	0.17	4.0
	Aug	.027	2.0	0.85	0.37	4.2
	Sept	.002	0.5	0.35	0.53	4.1
	Oct.	.013	1.6	0.39	0.88	3.9
	Dec.	.036	0.7	0.29	0.03	4.0
11-L	Feb	.009	0.8	0.21	0.29	4.1
	March	.024	0.5	0.12	0.07	4.1
	April	.022	1.2	0.27	0.12	4.0
	May	.014	3.0	0.13	0.19	4.1
	June	.046	1.0	0.16	0.54	3.8
	July	.032	1.3	0.68	0.22	3.8
	Aug	.038	1.0	0.39	0.78	3.9
	Sept	.016	1.4	0.28	0.81	3.6
	Oct	.016	2.0	0.40	1.28	3.4
	Dec	.076	3.3	0.16	0.15	3.8
184-L	Feb	.007	0.5	0.08	0.23	4.1
	March	.026	0.5	0.08	2.64	4.0
	April	.026	0.8	0.15	0.22	3.9
	May	.011	1.2	0.14	0.34	3.9
	June	.054	1.0	0.99	0.46	3.4
	July	.023	0.5	0.08	0.22	4.0
	Aug	.032	0.8	0.10	0.30	3.7
	Sept	.011	0.5	0.05	0.28	3.7
	Oct	.064	0.8	0.05	0.55	3.6
	Dec	.037	0.9	0.05	0.09	3.9

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[1] Instrument problems in the lab. This value is questionable.

TABLE 15. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1982.

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - - -	- - - - - - mg/l	- - - - - - - - - -		
0	Jan	--	--	--	--	--
	Feb	--	--	--	--	--
	March	.018	0.5	0.23	0.11	4.2
	April	.023	0.5	0.12	0.45	4.3
11-L	Jan	--	--	--	--	--
	Feb	--	--	--	--	--
	March	.008	2.2	0.20	0.12	4.0
	April	.030	4.5	0.10	0.20	4.2
184-L	Jan	--	--	--	--	--
	Feb	--	--	--	--	--
	March	.007	1.2	0.05	0.22	3.6
	April	.015	0.5	0.05	0.36	4.1

TABLE 16. RESULTS OF ANALYSES FOR SELECTED CATIONS IN THE PERCOLATE WATER AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1980.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - - - - - - - - - - -			mg/l	- - - - - - - - - - - - - -		
0	Jan	10.57	1.53	22.40	0.82	193	33	1.37
	March	1.15	0.72	12.60	2.14	106	33	1.37
	April	11.44	1.77	19.15	0.78	155	39	1.14
	May	1.65	0.75	6.65	10.01	167	37	1.71
	June	10.85	1.03	24.43	4.73	29	36	3.73
	July	14.67	1.59	33.69	4.05	84	40	4.10
	Aug	59.68	2.24	33.37	4.25	62	31	3.92
	Sept	90.27	4.62	72.45	0.68	<1	42	4.55
	Oct	13.67	3.69	67.80	0.53	1	29	3.11
	Nov	12.78	3.40	55.83	1.35	220	66	3.84
184-L	Jan	0.82	1.58	7.90	3.14	104	11.0	0.93
	March	0.82	1.10	4.51	2.20	42	5.0	0.82
	April	0.29	1.15	3.47	1.93	72	4.1	0.95
	May	0.46	1.58	3.83	2.54	43	13.0	0.70
	June	0.65	0.64	5.16	4.20	27	7.0	3.07
	July	1.40	0.80	4.70	4.15	27	7.7	2.51
	Aug	0.05	0.93	6.16	4.70	29	8.0	2.87
	Sept	0.13	0.94	6.41	4.42	15	6.3	4.17
	Oct	0.77	1.06	6.57	4.18	<1	0.7	2.58
	Nov	1.00	1.72	8.52	4.14	85	13.7	2.92

TABLE 17. RESULTS OF ANALYSES FOR SELECTED CATIONS IN THE PERCOLATE WATER AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1981.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		mg/l						
0	Feb	<1	0.04	0.2	2.22	123	77.4	4.52
	March	19.5	2.97	45.6	0.95	129	59.1	0.64
	April	16.0	1.25	15.8	1.00	94	36.1	0.82
	May	5.6	0.76	8.3	1.09	83	26.9	0.68
	June	9.9	1.08	10.5	1.37	89	32.6	0.72
	July	11.4	1.47	15.2	1.41	103	41.8	1.04
	Aug	5.1	1.48	12.6	1.51	103	40.3	1.43
	Sept	78.1	2.05	19.8	3.33	120	50.7	1.61
	Oct	7.4	2.17	22.1	1.19	116	53.9	1.99
	Nov	4.7	1.78	17.9	1.20	114	48.3	1.97
	Dec	5.1	1.70	19.5	1.04	113	32.8	1.52
184-L	Feb	0.07	1.28	4.50	2.55	56	8.2	0.47
	March	0.08	1.05	3.56	2.35	52	7.2	0.37
	April	0.06	0.99	3.32	3.07	47	6.7	0.48
	May	0.03	0.83	2.95	2.94	46	6.1	0.39
	June	0.28	0.85	3.06	3.41	43	6.1	0.44
	July	0.05	0.88	3.83	2.97	43	7.4	0.73
	Aug	0.27	0.96	3.28	3.56	48	6.9	0.57
	Sept	0.21	1.30	4.80	3.85	55	8.9	0.58
	Oct	0.25	1.55	5.65	3.95	63	10.7	1.29
	Nov	0.25	1.61	4.91	4.19	67	11.3	1.22
	Dec	0.11	1.66	5.73	3.73	63	11.5	1.00

Results of analyses of soil percolate water for selected cations for the control and highest sludge-treated plot are given in Tables 16 to 18. Results for all sludge-treated plots are given in Appendix, Tables A-12 to A-14. Concentrations of Mn, Al, K, Ca, Mg, and Na in percolate water at the 90 cm depth increased following sludge applications in 1977, while Fe decreased. In general, for the years 1980-1982, concentrations of Fe, Al, Ca, and Mg in percolate water from the sludge-treated plot were lower than those for the control plot. There was little difference in Mn, K, and Na concentrations of treated and control plots.

TABLE 18. RESULTS OF ANALYSES FOR SELECTED CATIONS IN THE PERCOLATE WATER AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1982

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha				mg/l				
0	Mar	0.87	0.61	6.27	0.97	78	26.6	0.99
	Apr	3.61	1.14	11.80	1.20	65	32.8	1.48
184-L	Mar	0.19	1.17	3.73	3.20	45	7.3	0.59
	Apr	0.38	1.25	4.27	3.66	49	7.4	0.89

Results of the analyses of soil percolate water for trace metals for all plots are given in Appendix, Table A-16 to A-18. Concentrations of trace metals in the percolate on all sludge-treated plots were extremely low during all three years (Tables 19 to 21). There appear to be no significant increases in the concentrations of any of the trace metals as a result of the sludge applications between 1980 and 1982, as was also the case for 1978 and 1979.

Results indicate that percolate water quality for 1980-82 met EPA drinking water standards with only one exception. Lead concentrations exceeded drinking water standards for only 3 of the 30 sampling months on the liquid sludge plot (11-L) and for only 2 on the dewatered sludge plot (184-L). It should be noted that the increases were minimal (0.16 mg/l being the highest value vs. 0.05 mg/l for drinking water standards) and pose no threat to human or animal health. In several cases the Pb concentrations on control plots also exceeded drinking water standards which indicates that occasional increases in Pb concentration are not resulting from sludge application.

When Cu and Zn concentrations in percolate water collected from the dewatered sludge plot are plotted over the 6-year period (1977-1982), three observations can be made: (1) except within two months after sludge application, Cu and Zn concentrations did not exceed drinking water standards; (2) Cu and Zn concentrations decreased markedly during the first year after

TABLE 19. SOIL PERCOLATE WATER ANALYSES FOR TRACE METALS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1980.

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha					mg/l			
0	Jan	0.04	0.37	0.04	0.06	0.09	<0.001	0.18
	March	0.03	0.32	0.03	0.09	0.04	<0.001	0.08
	April	0.07	0.51	0.02	0.06	0.07	0.001	0.14
	May	0.02	0.26	0.01	0.01	0.03	<0.001	0.05
	June	0.05	0.47	0.05	0.02	0.06	0.001	0.14
	July	0.07	0.68	0.05	0.02	0.05	<0.001	0.22
	Aug	0.07	1.23	0.07	0.07	0.07	<0.001	0.24
	Sept	0.14	1.71	0.11	0.06	0.18	0.001	0.42
	Oct	0.10	2.71	0.08	0.03	0.17	0.001	0.42
	Nov	0.09	0.72	0.04	0.19	0.19	0.001	0.30
11-L	Jan	0.06	0.93	0.02	0.09	0.15	0.001	0.30
	March	0.04	0.55	0.01	0.10	0.06	0.001	0.16
	April	0.05	0.50	0.01	0.06	0.07	0.002	0.14
	May	0.01	0.48	0.01	0.02	0.05	<0.001	0.11
	June	0.06	0.65	0.01	0.05	0.13	0.001	0.29
	July	0.05	1.43	0.03	0.05	0.22	<0.001	0.46
	Aug	0.03	0.89	0.01	0.05	0.10	0.001	0.29
	Sept	0.07	1.01	0.01	0.02	0.11	0.002	0.25
	Oct	0.10	1.22	0.02	0.04	0.27	0.001	0.30
	Nov	0.07	0.72	0.01	0.03	0.23	0.003	0.33
184-L	Jan	0.01	0.63	0.01	0.06	0.09	0.001	0.15
	March	0.01	0.34	0.01	0.04	0.04	0.001	0.09
	April	0.02	0.52	0.01	0.02	0.05	0.001	0.08
	May	0.01	0.48	0.01	0.01	0.05	<0.001	0.01
	June	0.02	0.44	0.01	0.01	0.05	<0.001	0.10
	July	0.02	0.51	0.01	0.02	0.05	0.001	0.12
	Aug	0.02	0.39	0.01	0.05	0.03	0.001	0.13
	Sept	0.02	0.58	0.03	0.03	0.04	0.001	0.10
	Oct	0.02	0.63	0.01	0.03	0.06	0.001	0.15
	Nov	0.03	0.59	0.01	0.07	0.12	0.001	0.15
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 20. SOIL PERCOLATE WATER ANALYSES FOR TRACE METALS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1981.

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha		mg/l						
0	Feb	0.01	0.12	0.01	0.05	0.02	0.008	0.01
	March	0.09	0.65	0.05	0.02	0.10	0.001	0.19
	April	0.06	0.26	0.04	0.02	0.08	0.001	0.09
	May	0.05	0.06	0.03	0.01	0.04	<0.001	0.08
	June	0.06	0.26	0.03	0.01	0.07	<0.001	0.08
	July	0.06	0.50	0.05	0.01	0.08	<0.001	0.13
	Aug	0.08	0.43	0.05	0.02	0.08	0.001	0.10
	Sept	0.04	0.34	0.05	0.01	0.09	0.001	0.12
	Oct	0.05	0.46	0.01	0.06	0.08	0.001	0.19
	Nov	0.04	0.41	0.01	0.06	0.05	<0.001	0.14
	Dec	0.04	0.48	0.05	0.08	0.06	0.001	0.14
1[illegible]-L	Feb	0.03	0.77	0.01	0.03	0.15	0.004	0.20
	March	0.04	0.40	0.02	0.02	0.11	0.002	0.10
	April	0.03	0.36	0.02	0.01	0.08	0.001	0.12
	May	0.03	0.12	0.02	0.02	0.06	0.001	0.11
	June	0.02	0.28	0.03	0.03	0.07	0.001	0.12
	July	0.04	0.79	0.03	0.01	0.08	0.001	0.13
	Aug	0.04	0.63	0.03	0.01	0.13	0.001	0.13
	Sept	0.06	0.74	0.04	0.01	0.18	0.002	0.26
	Oct	0.06	1.03	0.01	0.16	0.25	0.002	0.56
	Nov	0.04	0.85	0.01	0.01	0.19	0.002	0.42
	Dec	0.04	0.89	0.01	0.04	0.16	0.002	0.35
184-L	Feb	0.01	0.56	0.01	0.02	0.08	0.004	0.06
	March	0.03	0.34	0.01	0.01	0.09	0.003	0.04
	April	0.03	0.27	0.01	0.01	0.09	<0.001	0.06
	May	0.04	0.27	0.02	0.01	0.08	<0.001	0.03
	June	0.03	0.26	0.03	0.02	0.05	0.001	0.09
	July	0.03	0.32	0.03	0.01	0.07	0.001	0.05
	Aug	0.03	0.32	0.03	0.01	0.07	0.001	0.04
	Sept	0.03	0.22	0.03	0.01	0.06	0.001	0.03
	Oct	0.02	0.46	0.01	0.05	0.06	<0.001	0.15
	Nov	0.02	0.44	0.01	0.04	0.06	0.001	0.13
	Dec	0.02	0.55	0.01	0.01	0.08	0.001	0.12
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 21. SOIL PERCOLATE WATER ANALYSES FOR TRACE METALS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1982

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha	---------------------------mg/l---------------------------							
0	Mar	0.03	0.21	0.02	0.05	0.05	<0.001	0.11
	Apr	0.02	0.21	0.01	0.03	0.03	<0.001	0.06
11-L	Mar	0.02	0.22	0.01	0.04	0.06	0.001	0.13
	Apr	0.01	0.25	0.01	0.03	0.07	0.001	0.11
184-L	Mar	0.01	0.34	0.01	0.02	0.07	0.001	0.11
	Apr	0.01	0.37	0.01	0.01	0.06	<0.001	0.09
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

sludge application, and did not increase thereafter; (3) Cu concentrations on the sludged plot were consistently lower than those on the control plot, and Zn concentrations on the sludged plot were similar to or less than controls after the first two months following sludge application (Figures 6 and 7).

Total and fecal coliform analyses were conducted on all soil percolate water samples collected from January 23, 1980 to April 1982. Fecal coliform colonies were observed on only one sampling date (August 1, 1980). Four out of 9 lysimeters had fecal coliform colony counts of 1, 1, and 4 per 100 ml.

Groundwater Quality

Results of the analyses of groundwater well samples are given in Tables 22 to 27 and in Appendix Tables A-19 to A-25. Well 1 was drilled as a control outside the area of influence of the sludge applications. The values presented for Well 1 reflect the general groundwater quality for the disturbed mine site. Groundwater flow under the sludge-treated areas is toward Wells 2 and 3, with Well 2 reflecting the effect of the dewatered sludge applications and Well 3 reflecting the effect of the liquid digested sludge applications on groundwater quality. During the three year period of measurement the depth to the water table fluctuated in Well No. 1 from 4.5 to 5.5 m, in Well No. 2 from 2.6 to 3.4 m and in Well No. 3 from 1.5 to 2.0 m. Results indicate that the sludge applications have not had any significant effect on groundwater concentrations of orthophosphate-P, NO_3-N, NH_4-N or Org-N. Average monthly

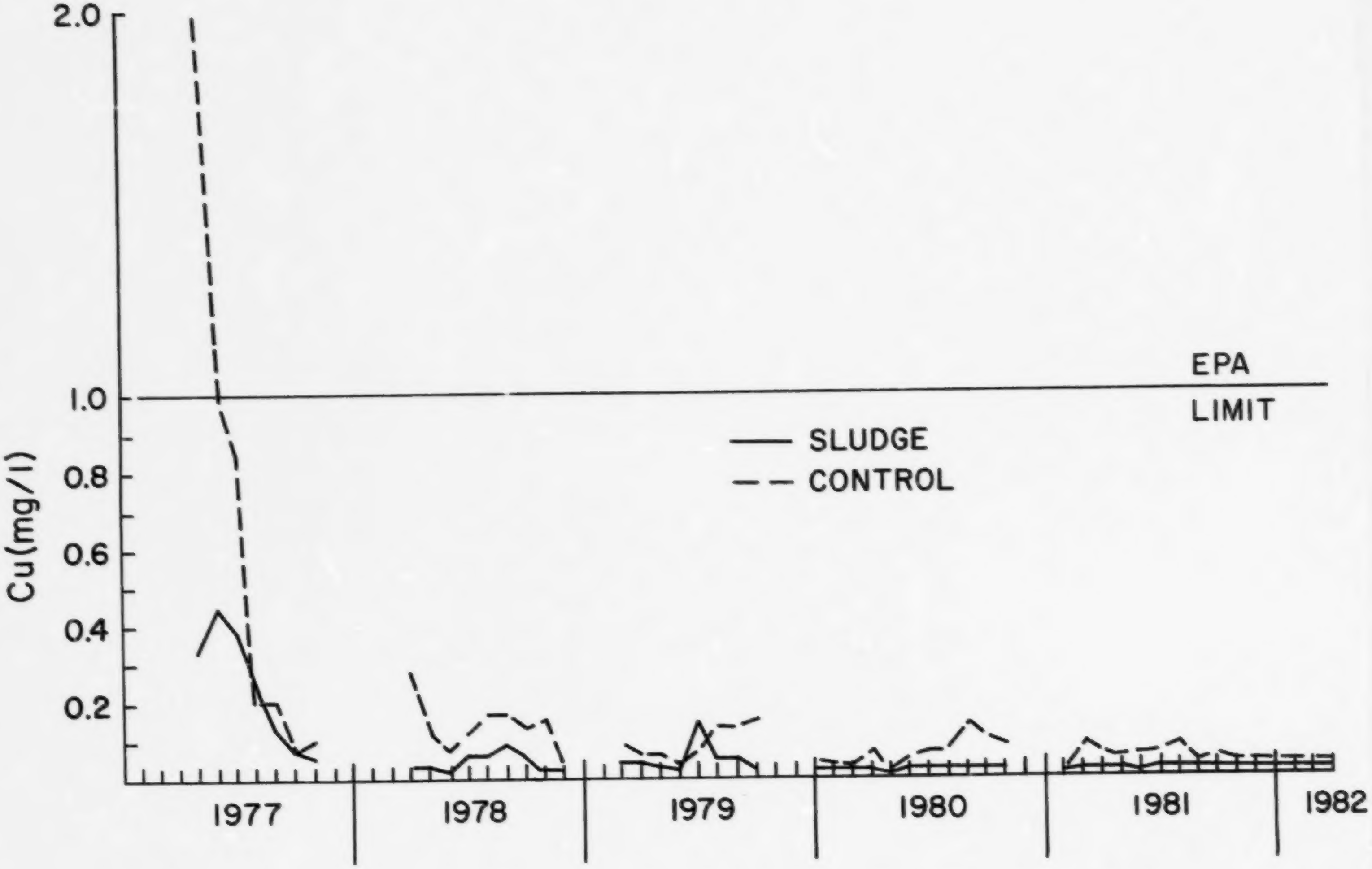

Figure 6. Copper concentration in soil percolate water on the area treated with 184 mt/ha of dewatered sludge on the Venango County demonstration plot.

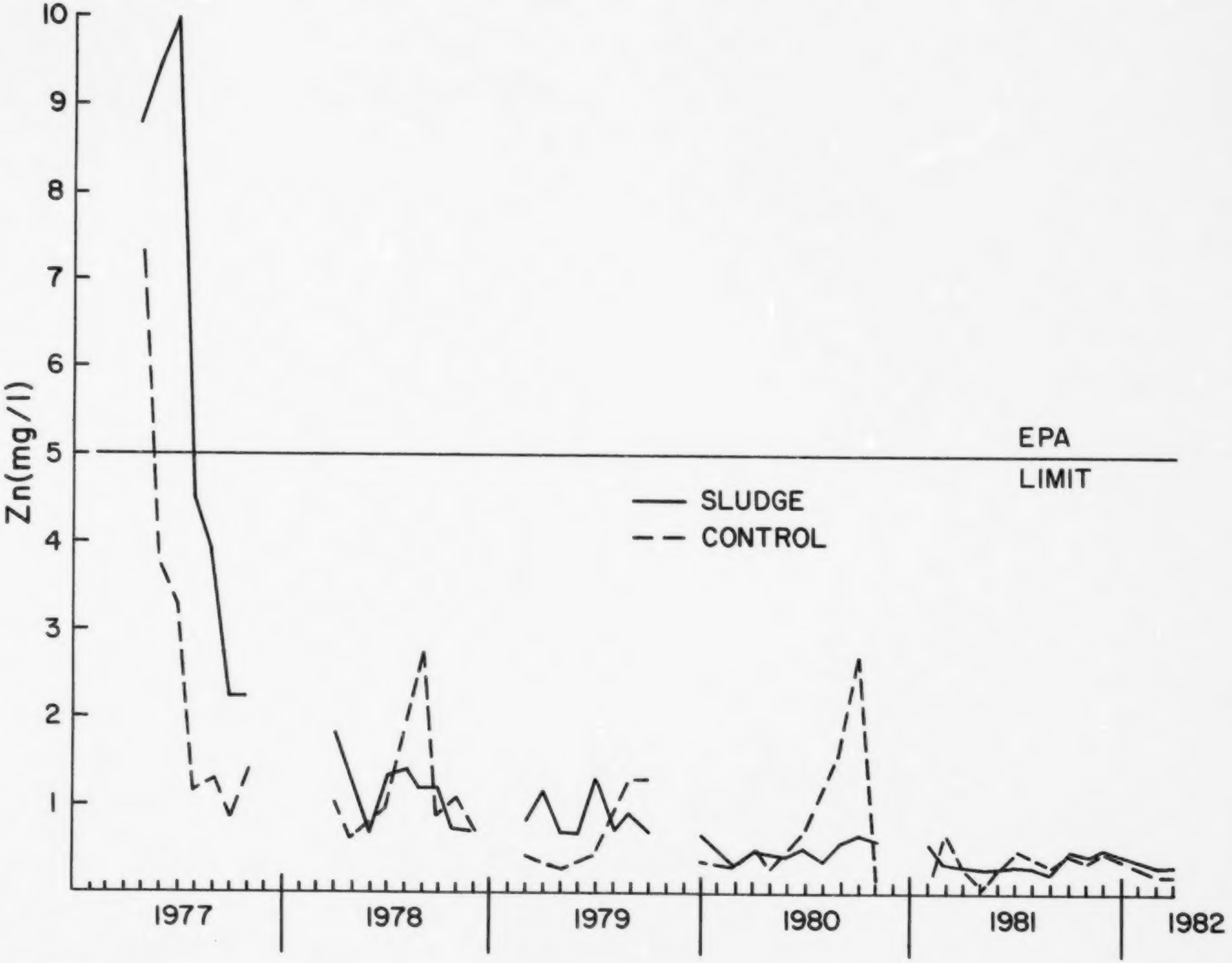

Figure 7. Zinc concentration in soil percolate water on the area treated with 184 mt/ha of dewatered sludge on the Venango County demonstration plot.

concentrations of NO_3-N were below 10 mg/l for all months sampled during the three year period (1980-82) (Tables 22-24) as was also the case during 1977-79. Results from Well 2 indicate that the applications of dewatered sludge did not significantly influence groundwater pH during the period 1980-82. The high pH values found in Well 3 were not due to the liquid sludge applications, but rather, reflect pretreatment conditions. The soil in the vicinity of this well initially had a high pH ranging from 6.2 to 7.5.

Results of analyses of groundwater samples for trace metals for 1980, 1981 and 1982 are given in Tables 25, 26 and 27. There appears to be no significant increase in any of the trace metal concentrations over the three-year period in either well (Well 2 and 3) influenced by the sludge applications. From 1977 to 1979 most of the concentrations were within the USEPA drinking water standards. From 1980 to 1982 Cu, Zn, Co, Cd, and Ni concentrations were within drinking water standards. In 1980 only Cr in groundwater collected from both the control and sludge-treated plots occasionally exceeded the standard of 0.05 mg/l, but by negligible amounts. The highest Cr concentration from the sludge-treated plots between 1980 and 1982 was 0.08 mg/l.

Between 1977 and 1979, most of the groundwater samples from both control and sludge-treated plots had Pb concentrations above the drinking water standard of 0.05 mg/l. However, between 1980 and 1982, 56% of the samples collected from the control plot, and only 38% of those collected from sludge-treated plots had Pb concentrations above 0.05 mg/l.

Total and fecal coliform analyses were conducted on groundwater samples collected during the period January 23, 1980 through April 1982. No fecal coliform colonies were observed for any sample.

Lake Water Quality

There are two lakes adjacent to the sludge-treated plots. The borders of the sludge-treated plots are approximately 50 m from the lakes. The results of lake water sample analyses for 1980-82 are given in Tables 28 to 30. Concentration of ortho-P, and ammonium-N and organic-N were consistently very low, as was the nitrate-N, which was well below the drinking water limits.

Results of analyses for Cu, Zn, and Cd in lake water samples collected in 1980, 1981, and 1982 are given in Tables 31 to 33. All values were below drinking water maximum concentration levels. Results of analyses of lake water samples for selected constituents are given in Appendix, Tables A-22 to A-24. Lake water quality for 1980-82 was similar to that for 1977-79.

WESTMORELAND COUNTY

Soils

In 1979, five soil pits were excavated in the sludge treatment area and two pits were excavated in the adjacent area for control data. Soil samples were collected at the 0-15, 15-30, 30-60, and 60-90 cm depth for background

TABLE 22. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1980.

Well No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		- - - - - - - - -	- mg/l -	- - - - - - - - -		
1	Jan	.003	0.5	2.70	0.50	5.7
	Feb	.003	0.5	2.30	1.10	5.8
	March	.000	0.5	2.60	1.00	5.7
	April	.013	0.5	2.68	--	5.6
	May	.004	0.5	3.05	0.00	5.4
	June	.000	0.5	3.08	0.40	5.6
	July	.000	0.5	3.20	0.00	5.1
	Aug	.000	0.5	3.14	0.02	5.2
	Sept	.012	1.5	0.96	1.70	5.3
	Oct	.008	0.5	3.18	0.00	5.3
	Nov	.007	0.5	0.06	0.00	5.4
2	Jan	.000	0.5	0.59	0.11	5.1
	Feb	.000	0.5	0.56	0.22	5.7
	March	.000	0.5	0.63	0.11	5.8
	April	.002	0.5	0.57	1.05	5.8
	May	.004	0.5	0.54	0.23	5.7
	June	.000	0.5	0.61	0.45	5.8
	July	.000	0.5	0.54	0.00	5.5
	Aug	.000	0.5	0.71	0.00	5.5
	Sept	.012	2.1	0.61	0.13	5.7
	Oct	.000	0.5	0.76	0.00	5.7
	Nov	.007	0.5	0.11	0.00	5.9
3	Jan	.000	0.5	0.05	0.21	6.4
	Feb	.000	0.5	0.05	0.17	6.5
	March	.000	0.5	0.05	0.19	6.5
	April	.005	0.5	0.06	0.34	6.4
	May	.010	0.5	0.06	0.37	6.7
	June	.005	0.5	0.14	0.37	6.3
	July	.000	2.1	0.12	0.16	6.2
	Aug	.004	0.5	0.22	0.49	6.5
	Sept	.038	5.2	0.54	0.06	7.1
	Oct	.004	0.5	0.21	0.08	6.4
	Nov	.009	1.1	0.05	3.10	6.7

TABLE 23. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1981.

Well No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		- - - - - - - - -	mg/l	- - - - - - - - -		
1	Feb	.001	0.5	2.35	1.57	5.3
	March	.010	0.5	2.05	1.25	5.7
	April	.010	0.5	2.58	0.00	5.5
	May	--	0.5	2.74	--	5.4
	June	.058	0.5	2.61	0.00	5.3
	July	.001	0.5	1.41	0.00	6.0
	Aug	.010	0.5	2.75	0.75	5.9
	Sept	.007	1.1	1.24	1.74	6.0
	Oct	.017	0.5	2.62	0.00	5.7
	Dec	.031	1.8	2.23	0.31	6.0
2	Feb	.015	0.5	0.47	0.35	5.7
	March	.010	0.5	0.48	0.34	6.0
	April	.001	0.5	0.62	0.04	5.8
	May	.001	0.5	0.61	0.50	5.9
	June	.035	0.5	0.61	0.32	5.5
	July	.001	0.5	0.59	0.15	6.1
	Aug	.005	0.5	0.66	0.19	6.0
	Sept	.002	0.5	0.33	0.42	6.4
	Oct	.017	0.5	0.76	0.21	6.0
	Dec	.026	1.4	0.65	0.24	6.2
3	Feb	.001	0.5	0.05	0.22	6.6
	March	.005	0.5	0.12	0.16	6.6
	April	.001	1.2	0.14	0.14	6.5
	May	.001	3.9	0.16	0.56	6.5[1]

[1] Monitoring discontinued due to vandalism.

TABLE 24. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1982.

Well No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		- - - - - - - - -	mg/l	- - - - - - - - -		
1	Feb	.017	2.4	3.17	0.53	5.7
	March	.002	0.5	3.29	0.00	5.7
	April	.005	0.5	0.29	0.00	6.0
2	Feb	.017	2.4	0.60	0.27	5.9
	March	.008	0.5	0.64	0.26	6.1
	April	.001	0.5	0.49	2.81	5.9

TABLE 25. GROUNDWATER ANALYSES FOR TRACE METALS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1980.

Well No.	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
					mg/l			
1	Jan	0.03	0.69	0.06	0.01	0.50	<0.001	0.38
	Feb	0.01	0.36	0.06	0.18	0.49	<0.001	0.35
	March	0.02	0.26	0.08	0.13	0.47	<0.001	0.31
	April	0.02	1.52	0.04	0.11	0.53	0.001	0.36
	May	0.01	0.54	0.01	0.08	0.46	<0.001	0.22
	June	0.01	0.01	0.01	0.01	0.01	<0.001	0.01
	July	0.14	1.68	0.06	0.07	0.59	0.001	0.47
	Aug	0.01	1.82	0.05	0.17	1.77	0.002	1.92
	Sept	0.04	0.69	0.09	0.17	0.53	<0.001	0.57
	Oct	0.02	0.74	0.04	0.08	0.53	<0.001	0.46
	Nov	0.27	1.50	0.03	0.01	0.73	0.002	0.47
2	Jan	0.07	1.74	0.05	0.05	1.15	<0.001	1.01
	Feb	0.01	0.98	0.06	0.16	1.04	0.001	0.76
	March	0.02	0.38	0.03	0.18	0.86	<0.001	0.57
	April	0.10	1.62	0.04	0.12	0.82	0.002	0.61
	May	0.01	0.95	0.01	0.15	0.82	<0.001	0.47
	June	0.01	0.72	0.04	0.02	0.76	<0.001	0.65
	July	0.08	1.12	0.06	0.04	0.78	0.001	0.74
	Aug	0.01	1.62	0.04	0.15	1.24	0.001	1.49
	Sept	0.01	0.60	0.08	0.18	0.76	<0.001	0.85
	Oct	0.02	0.94	0.04	0.04	0.72	<0.001	0.76
	Nov	0.16	0.92	0.02	0.14	0.61	0.001	0.45
3	Jan	0.01	0.29	0.02	0.01	0.01	<0.001	0.04
	Feb	0.01	0.13	0.03	0.08	0.02	<0.001	0.05
	March	0.03	1.18	0.03	0.17	0.03	<0.001	0.08
	April	0.01	0.40	0.01	0.04	0.02	0.001	0.03
	May	0.03	1.29	0.01	0.03	0.07	0.001	0.01
	June	0.01	0.15	0.01	0.02	0.01	<0.001	0.06
	July	0.01	0.77	0.01	0.01	0.01	0.001	0.05
	Aug	0.01	0.11	0.01	0.09	0.01	0.004	0.07
	Sept	0.01	0.09	0.02	0.11	0.01	<0.001	0.04
	Oct	0.01	0.30	0.01	0.01	0.01	<0.001	0.03
	Nov	0.03	0.37	0.01	0.02	0.01	<0.001	0.01
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 26. GROUNDWATER ANALYSES FOR TRACE METALS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1981.

Well No.	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
		- - - - - - - - - - - -			mg/l		- - - - - - - - - - - - - -	
1	Feb	0.03	0.42	0.01	0.03	0.48	0.011	0.27
	March	0.17	0.96	0.03	0.07	0.58	0.009	0.36
	April	0.12	0.96	0.03	0.03	0.48	0.001	0.30
	May	0.05	1.03	0.04	0.03	0.48	<0.001	0.25
	June	0.10	0.76	0.05	0.06	0.43	0.008	0.29
	July	0.08	1.53	0.05	0.02	0.44	0.002	0.23
	Aug	0.06	0.80	0.04	0.01	0.53	0.001	0.36
	Sept	0.04	0.95	0.05	0.03	0.45	0.001	0.36
	Oct	0.01	0.49	0.01	0.01	0.37	0.003	0.33
	Nov	0.01	0.71	0.01	0.11	0.39	0.001	0.34
	Dec	0.01	0.57	0.01	0.07	0.39	0.001	0.31
2	Feb	0.01	0.18	0.01	0.01	0.38	<0.001	0.26
	March	0.19	0.64	0.01	0.07	0.46	0.001	0.30
	April	0.02	0.20	0.03	0.03	0.46	<0.001	0.30
	May	0.07	0.96	0.03	0.04	0.53	<0.001	0.32
	June	0.08	0.36	0.04	0.03	0.45	<0.001	0.34
	July	0.04	1.25	0.03	0.03	0.44	0.002	0.31
	Aug	0.06	0.71	0.03	0.01	0.42	<0.001	0.30
	Sept	0.04	0.39	0.04	0.02	0.43	<0.001	0.36
	Oct	0.02	0.67	0.01	0.01	0.36	0.001	0.35
	Nov	0.01	0.29	0.01	0.16	0.35	<0.001	0.30
	Dec	0.02	0.53	0.01	0.09	0.32	0.005	0.28
3	Feb	0.01	1.29	0.01	0.01	0.02	<0.001	0.03
	March	0.07	0.15	0.01	0.02	0.01	0.001	0.01
	April	0.02	0.06	0.01	0.01	0.04	<0.001	0.02
	May	0.20	0.50	0.03	0.02	0.01	<0.001	0.01
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 27. GROUNDWATER ANALYSES FOR TRACE METALS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1982.

Well No.	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
		mg/l						
1	Feb	0.02	0.37	0.02	0.12	0.31	0.001	0.26
	March	0.02	0.43	0.02	0.01	0.29	<0.001	0.20
	April	0.04	0.60	0.03	0.06	0.33	<0.001	0.26
2	Feb	0.08	1.88	0.02	0.06	0.49	0.001	0.51
	March	0.04	0.58	0.01	0.04	0.38	<0.001	0.36
	April	0.03	0.53	0.02	0.04	0.41	<0.001	0.37
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 28. LAKE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1980.

Lake No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		- - - - - - - - - mg/l - - - - - - - - -				
1	April	.002	0.5	0.05	1.49	4.8
	May	.013	0.5	0.05	0.26	4.6
	June	.000	0.5	0.05	0.42	4.2
	July	.000	0.5	0.05	0.18	4.0
	Aug	.004	0.5	0.06	0.26	3.9
	Sept	.034	0.5	0.08	0.00	3.9
	Oct	.022	0.5	0.05	0.07	3.9
	Nov	.015	0.5	0.05	1.71	4.1
2	April	.005	0.5	0.05	0.40	6.1
	May	.013	0.5	0.05	0.26	6.2
	June	.000	0.5	0.05	0.47	6.2
	July	.000	1.0	0.05	0.24	6.4
	Aug	.008	0.5	0.05	0.37	6.6
	Sept	.012	2.3	0.06	0.04	6.3
	Oct	.008	0.5	0.05	0.11	6.3
	Nov	.003	0.5	0.05	1.06	6.2

TABLE 29. LAKE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1981.

Lake No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		- - - - - - - - -	mg/l	- - - - - - - - -		
1	April	.015	0.5	0.05	0.23	4.8
	May	.010	0.5	0.05	0.21	4.8
	June	.078	0.5	0.05	1.13	4.3
	July	.002	0.5	0.05	0.41	4.0
	Aug	.010	0.5	0.05	0.23	3.9
	Sept	.014	0.5	0.05	0.21	3.9
	Oct	.010	0.5	0.05	0.05	3.5
	Nov	--	--	--	--	--
	Dec	.011	1.6	0.05	0.05	3.8
2	April	.005	0.5	0.05	0.23	5.8
	May	.008	0.5	0.05	0.36	5.7
	June	.055	2.2	0.05	0.60	5.6
	July	.001	0.5	0.05	0.36	6.1
	Aug	.040	0.5	0.05	0.43	5.9
	Sept	.004	0.5	0.05	0.46	6.4
	Oct	.010	0.5	0.05	0.26	5.4
	Nov	--	--	--	--	--
	Dec	.031	1.3	0.05	0.15	5.9

TABLE 30. LAKE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1982.

Lake No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		- - - - - - - - - -	mg/l	- - - - - - - - - -		
1	March	.016	0.5	0.05	0.27	5.0
	April	.020	0.5	0.05	0.26	5.6
2	March	.001	0.5	0.05	0.27	5.8
	April	.002	0.5	0.05	0.05	6.3

TABLE 31. LAKE WATER ANALYSES FOR COPPER, ZINC, AND CADMIUM AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1980.

Lake No.	Month	Cu	Zn	Cd
		- - - - - - - -	mg/l	- - - - - - - -
1	April	0.01	0.24	0.001
	May	0.01	0.53	<0.001
	June	0.01	0.19	<0.001
	July	0.01	0.22	<0.001
	Aug	0.01	0.26	<0.001
	Sept	0.01	0.25	<0.001
	Oct	0.01	0.22	<0.001
	Nov	0.03	0.23	0.001
2	April	0.01	0.02	<0.001
	May	0.01	0.02	<0.001
	June	0.01	0.09	<0.001
	July	0.01	0.01	<0.001
	Aug	0.01	0.01	<0.001
	Sept	0.01	0.02	<0.001
	Oct	0.01	0.04	<0.001
	Nov	0.02	0.02	<0.001

TABLE 32. LAKE WATER ANALYSES FOR COPPER, ZINC, AND CADMIUM AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1981.

Lake No.	Month	Cu	Zn	Cd
			mg/l	
1	April	0.02	0.11	<0.001
	May	0.03	0.10	<0.001
	June	0.04	0.12	0.008
	July	0.01	0.13	<0.001
	Aug	0.01	0.15	<0.001
	Sept	0.01	0.08	0.001
	Oct	0.01	0.22	<0.001
	Nov	0.01	0.24	0.001
	Dec	0.01	0.73	0.001
2	April	0.01	0.01	<0.001
	May	0.03	0.01	<0.001
	June	0.04	0.04	<0.001
	July	0.01	0.15	<0.001
	Aug	0.01	0.01	<0.001
	Sept	0.01	0.01	<0.001
	Oct	0.01	0.39	<0.001
	Nov	0.01	0.01	<0.001
	Dec	0.01	0.32	<0.001

TABLE 33. LAKE WATER ANALYSES FOR COPPER, ZINC, AND CADMIUM AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1982.

Lake No.	Month	Cu	Zn	Cd
			mg/l	
1	March	0.01	0.12	0.001
	April	0.01	0.09	0.001
2	March	0.01	0.08	<0.001
	April	0.01	0.05	<0.001

chemical analyses. In 1980 and 1981 soils at various depths were again collected and analyzed (Tables 34-40 and A-25, 26).

Results of the pre-treatment soil analyses are given in Tables 34 and 35. The values presented for each plot are the averages for samples collected in all soil pits. Considering the extreme variability normally found in spoil banks, the results indicate that pre-treatment soil content of Kjeldahl nitrogen, total sulfur, and Bray phosphorus were quite similar over the 4-hectare demonstration site. Soil acidity, expressed as pH, was also quite uniform. Heavy metal concentrations in the soil were all extremely low. Results of the pre- and post-treatment soil analyses for Kjeldahl nitrogen, pH, and Bray phosphorus are given in Tables 36 and 37.

The amount of Bray phosphorus in the 0-15 cm soil depth was significantly increased initially by the 134 mt/ha sludge application and remained at a high level through the second year. Kjeldahl nitrogen significantly increased during the first year in the 0-15 cm depth. However, it decreased to pre-treatment levels by the end of the second year.

Soil pH was increased slightly at all depths and remained relatively constant through the 24 months after sludge application.

Of the exchangeable cations, only magnesium concentrations in the soil profile were increased the first year (Table 37). By the end of the second year (Table 39) most of the exchangeable cations showed significant increases in concentration at all depths. Concentrations of iron, aluminum, and manganese all decreased significantly over time following the sludge application. Iron concentration increased significantly in the 0-15 cm depth after two years. Manganese concentrations generally increased at all depths.

It is not possible to make a direct comparison between the data from the control and sludge plots or between different sludge application rates because of the inherent variability in the soil profile of such a disturbed site and the fact that the pre-treatment and post-treatment samples were not collected from the same pit. Thus, one can only interpret the data in terms of general trends.

Results of the analyses of the soil for extractable trace metals are given in Table 40. Trace metal concentrations were increased by the sludge application, particularly, at the 0-15 cm depth. Most increases were minimal and were within the normal range for soils as reported by Allaway (1968). Concentrations of all trace metals except cobalt continued to increase during the 24 month period after sludge application. Results of trace metal analyses of the soil samples collected on both the control and sludge-treated plots in 1980 and 1981 are given in Appendix Tables A-25 and A-26.

Vegetation

A site inspection on November 29, 1979, approximately 8 weeks after sludge application and seeding, indicated that a protective cover of winter rye had been established. Vegetation was approximately 5 cm in height (Figure 8). There was no evidence of any erosion on the sludge treatment area. It

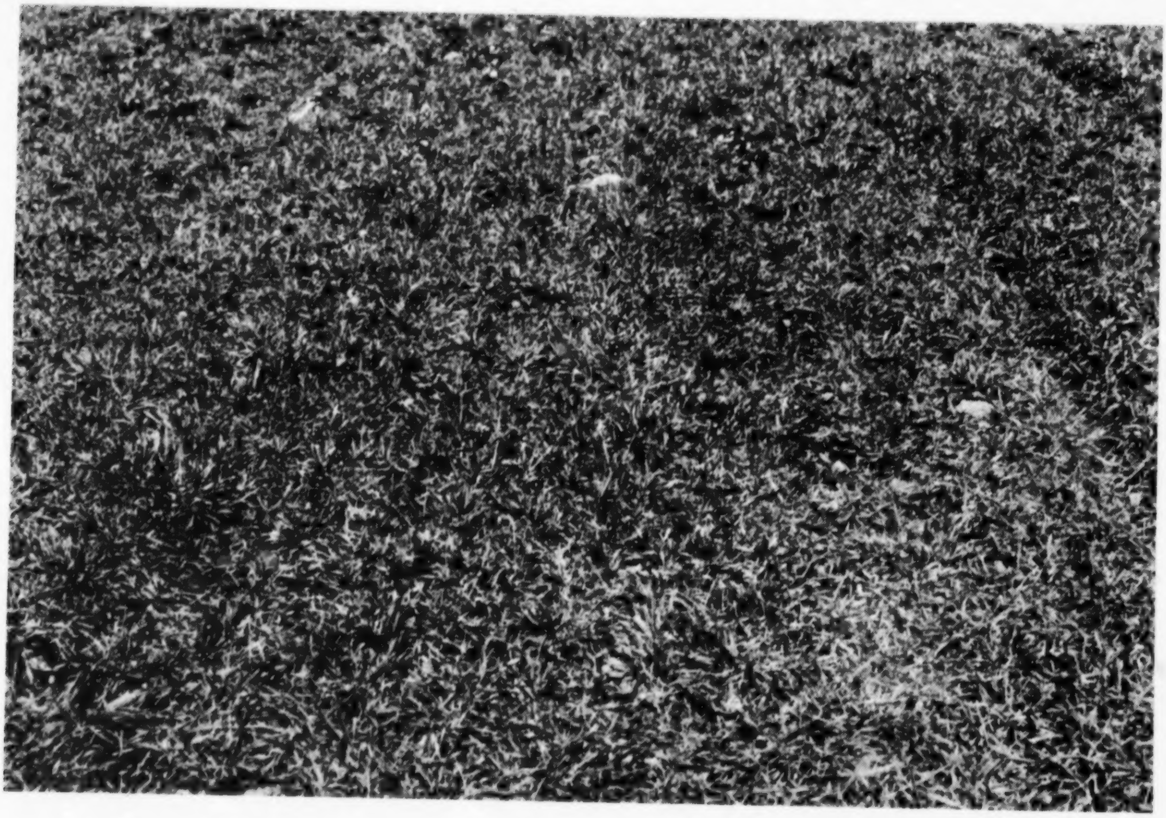

Figure 8. General view of the winter rye vegetation cover established several weeks after the fall application of sludge on the Westmoreland County demonstration plot.

TABLE 34. PRE-TREATMENT SOIL ANALYSIS FOR pH, KJELDAHL NITROGEN, TOTAL SULFUR AND BRAY PHOSPHORUS FOR SAMPLES COLLECTED AUGUST 1979 FROM THE WESTMORELAND DEMONSTRATION PROJECT

Soil Depth	pH	Kjeldahl Nitrogen	Total Sulfur	Bray Phosphorus
cm		%	%	ug/g
0-15	3.5	0.12	0.20	2.86
15-30	3.4	0.20	0.24	2.88
30-60	3.6	0.20	0.42	3.94
60-90	3.5	0.20	0.60	2.83

TABLE 35. PRE-TREATMENT SOIL ANALYSES FOR CATIONS AND HEAVY METALS COLLECTED AUGUST 1979 FROM THE WESTMORELAND COUNTY DEMONSTRATION PROJECT.

Soil Depth	Fe	Mn	Al	K	Ca	Mg	Na
cm				µg/g			
0-15	28.0	22.5	464	34.9	130	25.6	32.2
15-30	36.0	44.9	418	35.4	498	47.4	34.3
30-60	33.0	99.4	413	41.8	582	79.5	35.6
60-90	38.8	105.0	393	43.5	652	81.1	35.7
Soil Depth	**Cu**	**Zn**	**Cr**	**Pb**	**Co**	**Cd**	**Ni**
cm				µg/g			
0-15	4.63	3.63	0.04	0.55	0.17	0.001	0.23
15-30	6.06	5.23	0.06	0.21	0.50	0.001	0.42
30-60	8.29	8.94	0.05	0.92	1.38	<0.001	2.37
60-90	7.96	7.39	0.05	0.24	1.21	<0.001	1.95

TABLE 36. ANALYSES OF SOIL SAMPLES COLLECTED FROM THE WESTMORELAND DEMONSTRATION PROJECT FOR pH, KJELDAHL NITROGEN, AND BRAY PHOSPHORUS THIRTEEN MONTHS AFTER SLUDGE APPLICATION.

Sludge Application	Soil Depth	pH	Kjeldahl Nitrogen	Bray Phosphorus
mt/ha	cm		%	µg/g
0	0-15	4.8	0.15	2.50
	15-30	3.6	0.12	4.50
	30-60	3.1	0.31	10.00
134	0-15	5.5	0.55	19.35
	15-30	4.3	0.14	6.14
	30-60	3.9	0.13	8.45

TABLE 37. ANALYSES OF SOIL SAMPLES COLLECTED ON THE WESTMORELAND DEMONSTRATION PROJECT FOR EXCHANGEABLE CATIONS AND EXTRACTABLE IRON, ALUMINUM, AND MANGANESE THIRTEEN MONTHS AFTER SLUDGE APPLICATION.

Sludge Application	Soil Depth	K	Ca	Mg	Na	Fe	Mn	Al
mt/ha	cm	- - - - - - - - - - - - µg/g - - - - - - - - - - - - -						
0	0-15	59.0	1024	246	21.6	15.8	64.6	67.6
	15-30	59.8	1216	68	24.2	16.0	89.4	332.0
	30-60	28.8	1182	60	21.2	34.4	52.2	286.0
134	0-15	57.4	1254	273	16.4	11.4	24.2	45.5
	15-30	57.3	715	179	18.9	11.2	34.5	173.1
	30-60	59.3	686	167	18.9	17.0	39.4	165.3

TABLE 38. ANALYSES OF SOIL SAMPLES COLLECTED FROM THE WESTMORELAND DEMONSTRATION PROJECT FOR pH, KJELDAHL NITROGEN, AND BRAY PHOSPHORUS TWENTY-FOUR MONTHS AFTER SLUDGE APPLICATION.

Sludge Application	Soil Depth	pH	Kjeldahl Nitrogen	Bray Phosphorus
mg/ha	cm		%	µg/g
0	0-15	2.9	0.25	3.00
	15-30	3.0	0.25	0.15
	30-60	3.1	0.30	0.15
	60-90	3.0	0.25	1.85
134	0-15	5.4	0.25	144.35
	15-30	4.1	0.19	10.05
	30-60	3.6	0.21	4.27
	60-90	3.7	0.22	4.63

TABLE 39. ANALYSES OF SOIL SAMPLES COLLECTED ON THE WESTMORELAND DEMONSTRATION PROJECT FOR EXCHANGEABLE CATIONS AND EXTRACTABLE IRON, ALUMINUM AND MANGANESE TWENTY-FOUR MONTHS AFTER SLUDGE APPLICATION.

Sludge Application	Soil Depth	K	Ca	Mg	Na	Fe	Mn	Al
mt/ha	cm	- - - - - -	- - - - - -	- - - - - -	µg/g	- - - - - -	- - - - - -	- - - - - -
0	0-15	19.0	44	26	16.4	54	22	200
	15-30	35.2	136	40	42.6	67	38	215
	30-60	34.8	198	47	17.2	66	45	197
	60-90	31.8	846	75	18.6	80	79	231
134	0-15	59.9	1475	306	20.1	1744	27	54
	15-30	40.6	498	135	18.4	36	52	155
	30-60	45.3	432	113	19.0	59	102	166
	60-90	49.9	640	136	19.3	50	165	145

TABLE 40. ANALYSES OF SOIL SAMPLES COLLECTED EACH YEAR FOR EXTRACTABLE TRACE METALS ON THE WESTMORELAND COUNTY DEMONSTRATION PROJECT.

Sludge Application	Soil Depth	Sampling Date	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha	cm		- - - - - - - - - - - - - µg/g - - - - - - - - - - - -						
0	0-15	Aug 1979[1]	4.63	3.63	0.04	0.55	0.17	0.001	0.23
	15-30	Aug 1979	6.06	5.23	0.06	0.21	0.50	0.001	0.43
	30-60	Aug 1979	8.29	8.94	0.05	0.92	1.38	<0.001	2.37
134	0-15	Oct 1980[2]	22.07	77.64	5.28	14.39	1.04	0.64	4.74
	15-30	Oct 1980	4.42	7.58	0.30	2.08	0.51	0.11	1.95
	30-60	Oct 1980	3.98	4.33	0.08	1.03	0.58	0.04	1.80
134	0-15	Oct 1981[3]	43.09	173.45	17.17	23.53	0.93	1.71	9.80
	15-30	Oct 1981	6.13	10.90	0.52	2.37	0.67	0.11	2.85
	30-60	Oct 1981	4.51	5.93	0.18	1.35	1.89	0.02	2.97
Normal Range in Soils (Allaway, 1968)			2-100	10-300	5-3000	2-200	1-40	0.01-7.00	5-500

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[1] Aug 1979 samples represent pretreatment conditions.

[2] Oct 1980 samples were collected thirteen months after sludge application.

[3] Oct 1981 samples were collected twenty-four months after sludge application.

appeared that sufficient vegetation was established to protect the site from erosion and runoff over the winter season. This was confirmed by a site inspection on March 28, 1980. The entire sludge-treated area was covered by a vegetative cover ranging from 5 to 10 cm in height. On the basis of ocular estimates, the percentage areal cover ranged from 80 to 90 percent. There was no evidence of surface runoff or erosion from the sludge-treated area. However, some erosion did occur from barren areas upslope of the sludge-treated area. The sediment-laden surface runoff from these areas was dispersed as soon as it encountered the sludge-treated plot which had been roughened by contour chisel plowing to incorporate the sludge.

By June, 1980 the winter rye seed stalks were well over 5 feet tall (Figure 9) and the entire sludge-treated area had developed a 100 percent vegetative cover. The rye was not harvested but rather the straw was allowed to collapse to provide an additional protective organic mulch on the site until the birdsfoot trefoil was well established. By September 1981 (2 years after sludge application), the entire site was predominantly occupied by a cover of birdsfoot trefoil.

Vegetation growth responses were evaluated at the end of each growing season. Measurements of vegetation heights were taken at 10 locations along each of two transect lines. Average vegetation heights were 68 and 64 cm in 1980 and 1981, respectively. These measurements reflect the average height of the grasses (tall fescue and orchardgrass) and the birdsfoot trefoil and do not include the tall seed stalks of the winter rye.

To determine dry matter production, twenty, 0.1 m^2 samples of the vegetative cover were collected on the sludge-treated plot. Average dry matter production was 11 and 31 mt/ha in 1980 and 1981, respectively.

At the end of each growing season individual samples of the two grasses and one legume species were collected from the sludge-treated area for foliar analysis. A few plants of tall fescue and orchardgrass were found growing on the surface runoff control berms surrounding the sludge-treated plot. These berms did not receive sludge but lime and fetilizer were applied with the seed. Vegetation establishment on these berms was very poor and most of the berms were highly eroded. Foliar samples from these plants were also collected and analyzed for comparison. Results of these analyses are given in Tables 41 to 44.

Results of the foliar analyses for trace metals indicated that the sludge application did increase concentrations of some of the elements. However, these increases were minimal and were well below the suggested tolerance levels and no phytotoxicity symptoms were observed. Results also indicate that the concentrations of Cu, Co, and Ni were higher in the grass species on the control area than the same species on the sludge-treated plot.

Concentrations of Cu, Zn, and Cd increased during the second year in birdsfoot trefoil and orchardgrass. All other elements decreased in concentration. Similarly, all trace metal concentrations in tall fescue decreased by the end of the second growing season.

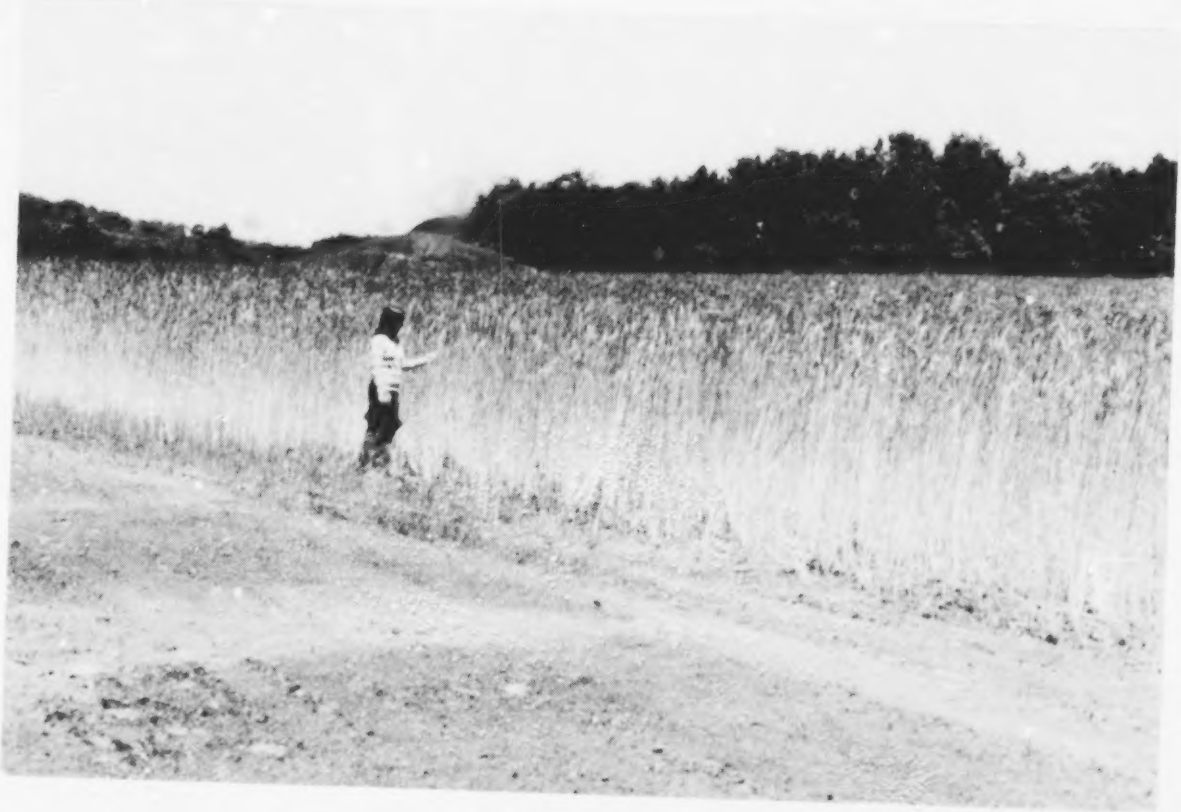

Figure 9(A). Border view of winter rye vegetation the following spring after a fall application of 134 mt/ha of a compost-cake mixture of sludge on the Westmoreland County demonstration plot.

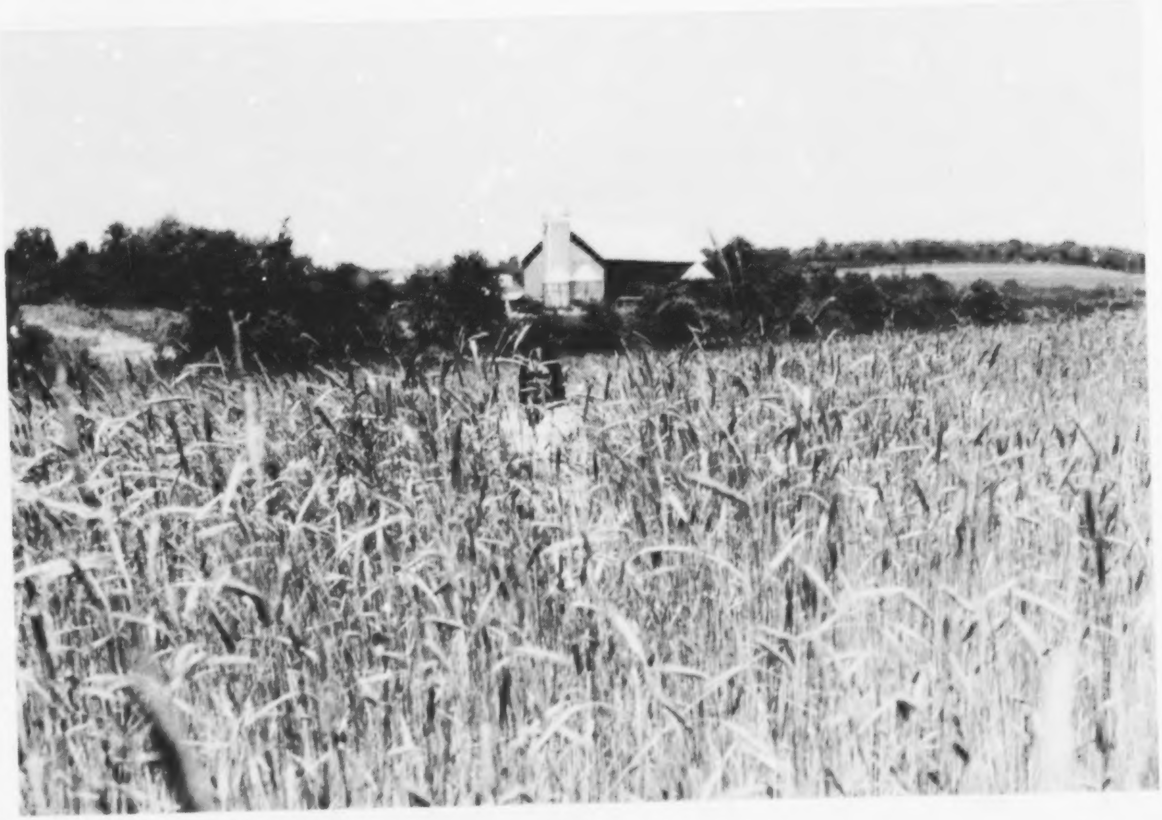

Figure 9(B). General view of a technician standing in the tall winter rye vegetation which developed in the spring following the fall application of sludge on the Westmoreland County demonstration plot.

TABLE 41. MEAN FOLIAR CONCENTRATIONS OF SELECTED CONSTITUENTS FROM SAMPLES COLLECTED IN 1980 FROM THE WESTMORELAND COUNTY DEMONSTRATION SITE TREATED WITH 134 mt/ha OF SLUDGE

Species	N	P	K	Ca	Mg	Mn	Fe	B	Al
	%					µg/g			
Birdsfoot Trefoil	3.27	0.26	1.99	1.30	0.38	138	121	34	74
Orchardgrass	1.72	0.54	2.78	0.37	0.45	289	119	9	77
Tall Fescue	0.98	0.22	0.91	0.28	0.18	775	188	9	106

TABLE 42. MEAN FOLIAR CONCENTRATIONS OF TRACE METALS FROM SAMPLES COLLECTED IN 1980 FROM THE WESTMORELAND COUNTY DEMONSTRATION SITE TREATED WITH 134 mt/ha OF SLUDGE

	Cu	Zn	Cr	Pb	Co	Cd	Ni
	µg/g						
Birdsfoot Trefoil							
	8.5	24.6	1.6	3.5	1.9	0.53	6.8
Orchardgrass							
	11.3	41.9	1.4	2.8	1.3	0.89	5.9
Tall Fescue							
	6.2	21.3	1.2	2.3	1.3	0.35	3.6
Suggested*† Tolerance Levels	150	300	2	10	5	3	50

*Melsted (1973)
†Council for Agricultural Science and Technology (1976)

TABLE 43. MEAN FOLIAR CONCENTRATIONS OF SELECTED CONSTITUENTS FROM SAMPLES COLLECTED IN 1981 FROM THE WESTMORELAND COUNTY DEMONSTRATION SITE TREATED WITH 134 mt/ha OF SLUDGE

Sludge Application	N	P	K	Ca	Mg	Mn	Fe	B	Al
mt/ha	%					µg/g			
				Birdsfoot Trefoil					
134	3.74	0.30	2.01	1.15	0.33	121	95	34	41
				Tall Fescue					
0	0.87	0.20	1.58	0.23	0.22	289	608	8	551
134	1.54	0.42	2.34	0.49	0.40	144	71	7	48
				Orchardgrass					
0	1.18	0.24	1.80	0.28	0.20	373	1347	13	680
134	2.57	0.43	3.12	0.39	0.38	147	87	8	48

TABLE 44. MEAN CONCENTRATIONS OF TRACE METALS IN VEGETATION FOLIAR SAMPLES COLLECTED AT THE END OF THE 1981 GROWING SEASON FROM THE WESTMORELAND COUNTY DEMONSTRATION PROJECT

Sludge Application	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha	μg/g						
				Birdsfoot Trefoil			
134	10.6	42.9	<0.1	0.1	1.3	0.57	4.4
				Orchardgrass			
0	7.3	18.3	<0.1	<0.1	0.7	0.18	3.3
134	15.3	43.1	<0.1	<0.1	<0.1	0.39	1.3
				Tall Fescue			
0	10.3	14.0	<0.1	<0.1	0.9	0.29	2.7
134	8.4	31.2	<0.1	<0.1	<0.1	0.49	1.6
Suggested*† Tolerance Levels	150	300	2	10	5	3	50

*Melsted (1973)

†Council for Agricultural Science and Technology (1976)

Percolate Water Quality

Results of the analyses of soil percolate water samples for the sludge-treated and control areas from 1980 to 1982 are given in Tables 45 to 50, and Appendix Tables A-27 to A-29. The data for all years following sludge application (1979-82) indicate that sludge had no effect on concentrations of ortho-P, nitrate-N, ammonium-N, organic-N, or on pH of soil percolate. Concentrations of NO_3-N were extremely low before sludge application and remained at these low levels during all years following. NO_3-N concentrations were consistently within USEPA drinking water standards.

Sludge application did not affect percolate concentrations of Fe or Na. Manganese, Al, Ca and Mg concentrations of percolate water from the sludge-treated plot decreased over the 4-year period after sludge application compared to percolate water from control plots (Tables A-27 to A-29).

Concentrations of Cr, Pb, and Cd in the percolate (Tables 48-50) did not appear to be affected by sludge application from 1979 to 1982. From 1980-82 Cu, Zn, Co, and Ni concentrations were somewhat lower in percolate collected

TABLE 45. SOIL PERCOLATE ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1980.

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - - - -	- - - -	mg/l - - - -	- - - - -	- - - -
0	Jan	.011	0.5	0.40	0.22	3.2
	March	.015	0.5	0.08	0.00	3.2
	April	.014	0.5	0.50	0.51	3.4
	May	.026	0.5	1.20	0.16	3.2
	June	.012	0.8	1.34	0.00	3.0
	July	.044	0.8	1.88	0.02	3.0
	Aug	.008	1.0	1.32	0.00	3.0
	Sept	.010	0.8	1.46	0.44	3.0
	Oct	.040	1.0	0.62	0.10	3.0
134	Jan	.063	0.6	0.70	0.19	3.5
	March	.023	0.5	0.09	0.00	3.5
	April	.038	0.6	0.96	1.04	3.6
	May	.015	0.7	1.63	0.12	3.7
	June	.031	0.6	1.96	0.27	3.4
	July	.064	0.9	2.75	0.58	3.4
	Aug	.024	0.7	2.93	1.54	3.5
	Sept	.012	0.7	1.71	0.31	3.3
	Oct	.040	1.2	1.77	0.24	3.7

TABLE 46. SOIL PERCOLATE ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1981.

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - -	- - - - -	mg/l	- - - - -	- - - - -
0	March	.015	0.5	0.05	0.00	3.2
	April	.006	0.5	0.69	0.02	3.1
	May	.005	0.5	0.41	0.00	3.1
	June	.098	0.8	0.98	0.00	3.2
	July	.062	1.6	3.06	0.00	3.2
	Aug	.037	0.8	1.58	0.00	3.0
	Sept	.034	2.1	1.52	0.11	3.0
	Oct	.046	1.2	1.10	3.31	2.9
	Dec	.038	2.4	0.60	0.18	3.2
134	Feb	.006	0.7	0.86	0.45	3.9
	March	.023	0.5	0.77	0.36	3.8
	April	.032	0.8	0.24	0.29	3.1
	May	.023	0.5	0.73	0.11	3.6
	June	.047	0.9	0.75	0.87	3.3
	July	.052	1.8	1.74	0.20	3.5
	Aug	.041	0.7	1.54	0.24	3.5
	Sept	.064	1.6	0.58	0.35	3.1
	Oct	.030	1.5	0.97	0.10	3.3
	Dec	.057	1.2	0.33	0.16	3.5

TABLE 47. SOIL PERCOLATE ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1982.

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		mg/1				
0	Jan	.026	0.9	0.32	0.05	3.2
	March	.012	1.0	0.27	0.27	3.2
	April	.001	0.5	0.24	0.13	3.3
134	Jan	.028	0.8	0.45	0.03	3.4
	March	.049	0.7	0.40	0.31	3.9
	April	.012	1.0	0.63	0.15	3.8

TABLE 48. SOIL PERCOLATE ANALYSES FOR TRACE METALS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1980.

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha					mg/l			
0	Jan	0.12	2.45	0.02	0.07	0.83	0.015	0.84
	March	0.11	1.46	0.02	0.05	0.22	0.002	0.47
	April	0.10	1.14	0.01	0.03	0.22	0.010	0.27
	May	0.15	2.41	0.01	0.06	0.62	0.005	0.70
	June	0.17	2.14	0.02	0.10	0.30	0.008	0.60
	July	0.17	2.23	0.02	0.04	0.30	0.008	0.59
	Aug	0.16	2.39	0.02	0.01	0.35	0.009	0.66
	Sept	0.16	2.71	0.01	0.05	0.35	0.002	0.73
	Oct	0.16	3.07	0.01	0.07	0.35	0.014	0.76
134	Jan	0.11	3.36	0.01	0.08	1.12	0.017	0.86
	March	0.05	1.20	0.01	0.04	0.42	0.003	0.37
	April	0.08	1.40	0.01	0.04	0.35	0.012	0.33
	May	0.04	1.62	0.01	0.02	0.48	0.005	0.44
	June	0.07	2.38	0.01	0.05	0.28	0.006	0.40
	July	0.05	1.68	0.01	0.07	0.26	0.008	0.45
	Aug	0.04	1.26	0.01	0.04	0.26	0.005	0.43
	Sept	0.05	1.78	0.01	0.03	0.13	0.006	0.40
	Oct	0.05	1.64	0.01	0.03	0.26	0.005	0.47
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 49. SOIL PERCOLATE ANALYSES FOR TRACE METALS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1981.

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha		- - - - - - - - - - - - - -			mg/l - - - - - - - - - - - - -			
0	March	0.15	2.87	0.02	0.04	0.70	0.018	0.91
	April	0.14	1.86	0.01	0.01	0.45	0.008	0.59
	May	0.27	3.11	0.02	0.03	0.81	0.009	0.97
	June	0.14	2.15	0.05	0.01	0.39	0.014	0.56
	July	0.15	2.33	0.04	0.02	0.35	0.015	0.50
	Aug	0.10	1.62	0.03	0.01	0.19	0.005	0.21
	Sept	0.16	2.68	0.05	0.01	0.55	0.011	0.60
	Oct	0.17	2.58	0.01	0.03	0.61	0.012	0.76
	Nov	0.21	3.32	0.02	0.02	0.91	0.009	1.23
	Dec	0.14	2.66	0.01	0.01	0.67	0.013	0.78
134	Feb	0.06	1.61	0.01	0.04	0.46	0.008	0.54
	March	0.05	1.47	0.01	0.03	0.32	0.008	0.37
	April	0.05	0.94	0.01	0.07	0.27	0.006	0.27
	May	0.13	1.11	0.01	0.02	0.29	0.006	0.32
	June	0.12	1.13	0.04	0.01	0.23	0.006	0.28
	July	0.08	1.17	0.04	0.01	0.25	0.006	0.28
	Aug	0.09	0.97	0.03	0.01	0.25	0.007	0.26
	Sept	0.08	0.95	0.04	0.01	0.26	0.005	0.27
	Oct	0.06	1.14	0.01	0.01	0.28	0.005	0.34
	Nov	0.07	1.12	0.01	0.03	0.22	0.004	0.28
	Dec	0.07	1.21	0.01	0.03	0.37	0.004	0.36
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 50. SOIL PERCOLATE ANALYSES FOR TRACE METALS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1982.

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha		- - - - -	- - - - -	- - - - -	mg/l	- - - - -	- - - - -	- - - - -
0	Jan	0.13	2.43	0.03	0.01	0.64	0.015	0.74
	March	0.14	2.71	0.02	0.02	0.77	0.010	1.02
	April	0.14	2.38	0.01	0.12	0.71	0.009	0.91
134	Jan	0.06	1.33	0.02	0.01	0.38	0.005	0.39
	March	0.06	0.99	0.01	0.01	0.32	0.005	0.36
	April	0.06	0.98	0.01	0.06	0.32	0.004	0.32
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agriclutral land. No criteria set for drinking water.

from the sludge-treated site than from the control area. All trace metal concentrations were within drinking water standards for all years, except Pb which occasionally exceeded the standard of 0.05 mg/l by a negligible amount (the highest Pb concentration over the 4-year period was 0.08 mg/l).

Total and fecal coliform analyses were conducted on all soil percolate water samples collected during the period January 4, 1980 to April 1982. No fecal coliform colonies were observed for any sample.

Groundwater Quality

Results of the analyses of groundwater well samples are given in Tables 51 to 56 and Appendix Tables A-30 to A-32 for Well 1. Depth to the water table ranged from 1.1 m to 1.5 m between 1980 and 1982. Well 2 was an artesian well capped in April 1980. Sludge application did not have any apparent effect on the concentration of any constituent, except pH which decreased from an average of 11.4 in 1979 before sludge application to an average of 4.5 in 1982. The concentration of NO_3-N in Well 1 was slightly higher than the potable water standard (17 mg/l vs. 10 mg/l) before sludge application in 1979, but was below the potable water limit the first month following sludge application, and remained at low levels through 1982 (Tables 51 to 53). Concentrations of all trace metals except Pb were within the potable water limit (Tables 54 to 56). Lead concentrations exceeded 0.05 mg/l occasionally on both control and sludge-treated areas from 1979 through 1982. The amounts by which groundwater Pb exceeded this limit were minimal and pose no threat to human or animal health.

Total and fecal coliform analyses were conducted on all groundwater samples collected during the period January 4, 1980 to April 1982. Fecal coliform colonies were observed on only one sampling date (October 15, 1980), one year after sludge application. Fecal coliform count observed in that sample was one per 100 ml.

LACKAWANNA COUNTY

Soils

In 1978 four soil pits were excavated in each sludge treatment and in an adjacent area for control data. Soil samples collected at the 0-15, 15-30, 30-60, and 60-90 cm depth were analyzed for background concentrations. In 1979 and 1982, soils at various depths were again collected and analyzed (Tables 57-60). There was a considerable increase in soil pH at the 0-15 and 15-30 cm depths between 1978 and 1982 (3.5-3.8 in 1978 to 4.2-5.9 in 1982) as shown in Table 57. Changes in concentrations of exchangeable cations, Bray Phosphorus, and Kjeldahl nitrogen are given in Table 58. Decreases in concentrations of Fe, Al, and Mn are given in Table 59. On both sludge treatments, trace metal concentrations at the 0-15 cm soil depth generally increased over the 4-year period. The increased extractable metal concentrations in 1982, however, were all within the normal ranges of total metal concentrations in soils reported by Allaway (1968), and were in fact at the extreme lower ends of those ranges (Table 60). For additional comparison, trace metal concentrations at the 0-15 cm depth for several Pennsylvania prime farmland soil types

TABLE 51. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1980

Well No.	Month and Year	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		mg/l				
Well 1	Sep 1979[1]	0.015	17.6	0.54	0.62	10.3
	Oct	0.033	7.1	0.72	0.63	11.9
	Nov	0.013	< 0.5	1.68	0.00	11.5
	Dec	0.015	< 0.5	0.52	0.76	11.8
	Jan 1980	0.007	< 0.5	0.75	0.33	11.4
	Feb	0.003	1.3	0.75	0.31	10.5
	Mar	0.005	1.9	0.16	0.00	9.1
	Apr	0.023	1.3	0.40	0.00	7.9
	May	0.000	0.5	0.57	0.26	6.5
	Jun	0.000	1.1	0.62	0.30	6.6
	Jul	0.067	>100.0[3]	2.42	0.00	1.1
	Aug	0.013	6.1	0.54	0.57	7.0
	Sep	0.031	0.5	1.22	0.66	7.5
	Oct	0.007	0.5	0.95	0.07	7.2
Well 2	Sep 1979[1]	0.004	1.7	0.63	0.58	7.5
	Oct	0.005	1.0	0.66	0.49	7.7
	Nov	<0.001	< 0.5	1.64	0.00	7.2
	Dec	0.005	< 0.5	0.64	0.48	7.1
	Jan 1980	0.005	0.5	0.70	0.54	7.0
	Feb	0.007	0.5	0.68	0.10	6.9
	Mar[2]	0.005	0.5	0.30	0.00	6.7

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[1] September 1979 values represent pre-treatment conditions.

[2] Artesian well capped in April 1980.

[3] Probably due to ionic interferences with NO_3- electrode.

TABLE 52. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1981

Well No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		mg/1				
Well 1	Jan	--	--	--	--	--
	Feb	.005	1.0	0.05	0.20	7.6
	Mar	.001	0.5	0.42	0.60	6.6
	Apr	.006	0.5	0.05	0.00	6.3
	May	.001	0.5	0.64	0.53	6.2
	Jun	.015	1.5	0.53	0.40	5.5
	Jul	.015	0.5	0.58	0.28	5.7
	Aug	.007	0.5	0.73	0.28	5.6
	Sep	.042	2.8	0.65	1.35	4.0
	Oct	.012	1.6	4.93	0.79	4.1
	Nov	--	--	--	--	--
	Dec	.034	3.8	6.27	2.59	3.8

TABLE 53. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1982

Well No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		mg/1				
Well 1	Jan	0.030	2.1	7.30	0.00	3.9
	Feb	0.006	1.1	5.61	1.59	4.1
	Mar	0.017	0.5	3.07	1.21	4.9
	Apr	0.001	0.5	2.56	1.00	5.0

TABLE 54. GROUNDWATER ANALYSES FOR TRACE METALS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1980

Well No.	Month and Year	Cu	Zn	Cr	Pb	Co	Cd	Ni
					mg/l			
Well 1	Sep 1979[1]	0.05	0.23	0.03	0.14	0.03	<0.001	0.05
	Jan 1980	0.04	0.30	0.01	0.20	0.02	0.001	0.03
	Feb	0.01	0.07	0.01	0.02	0.04	<0.001	0.03
	Mar	0.01	0.11	0.03	0.01	0.03	<0.001	0.02
	Apr	0.05	0.13	0.02	0.06	0.03	<0.001	0.03
	May	0.05	0.31	0.01	0.04	0.05	<0.001	0.01
	Jun	0.04	0.10	0.01	0.11	0.01	<0.001	0.02
	Jul	0.11	0.14	0.02	0.15	0.01	<0.001	0.06
	Aug	0.14	0.28	0.01	0.04	0.01	<0.001	0.03
	Sep	0.01	0.05	0.01	0.06	0.01	<0.001	0.02
	Oct	0.01	0.04	0.01	0.01	0.01	<0.001	0.04
Well 2	Sep 1979[1]	0.02	0.17	0.02	0.03	0.24	<0.001	0.17
	Jan 1980	<0.01	0.12	<0.01	0.08	0.10	0.001	0.04
	Feb	<0.01	0.04	<0.01	0.02	0.07	0.001	0.06
	Mar	<0.01	0.02	0.03	0.08	0.07	0.003	0.09
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

[1] September 1979 values represent pre-treatment conditions.

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 55. GROUNDWATER ANALYSES FOR TRACE METALS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1981

Well No.	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
					mg/l			
Well 1	Feb	0.06	0.06	0.01	0.01	0.09	<0.001	0.23
	Mar	0.02	0.10	0.01	0.07	0.11	<0.001	0.21
	Apr	0.04	0.40	0.01	0.08	0.14	0.011	0.24
	May	0.03	0.50	0.01	0.01	0.10	0.001	0.17
	Jun	0.01	0.12	0.04	0.01	0.09	0.002	0.26
	Jul	0.05	0.68	0.04	0.03	0.09	0.015	0.22
	Aug	0.06	0.46	0.04	0.01	0.04	0.002	0.15
	Sep	0.28	0.37	0.04	0.03	0.10	0.002	0.22
	Oct	0.05	0.35	0.02	0.06	0.14	<0.001	0.24
	Nov	0.05	0.26	0.01	0.01	0.15	<0.001	0.20
	Dec	0.09	0.53	0.01	0.05	0.14	<0.001	0.24
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 56. GROUNDWATER ANALYSES FOR TRACE METALS AT THE WESTMORELAND COUNTY DEMONSTRATION PROJECT DURING 1982

Well No. 1	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
Well 1	Jan	0.07	1.19	0.02	0.01	0.23	0.002	0.30
	Feb	0.08	1.20	0.01	0.13	0.12	0.002	0.18
	Mar	0.03	0.27	0.01	0.02	0.09	0.001	0.20
	Apr	0.11	0.29	0.01	0.09	0.10	0.003	0.21
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 57. CHANGES IN SOIL pH FOLLOWING SLUDGE APPLICATION AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT.

Sludge Application	Depth	Soil pH		
		1978[1]	1979	1982
mt/ha	cm			
0	0-15	4.0	-	3.5
	15-30	3.9	-	3.6
80	0-15	3.8	3.8	5.9
	15-30	3.9	3.5	4.3
108	0-15	3.6	3.6	5.8
	15-30	3.7	3.6	4.2

[1] 1978 values represent pretreatment conditions.

TABLE 58. CHANGES IN CONCENTRATIONS OF KJELDAHL NITROGEN, BRAY PHOSPHORUS, AND EXCHANGEABLE CATIONS FROM SOILS COLLECTED AT VARIOUS DEPTHS FOLLOWING SLUDGE APPLICATION AT 80 AND 108 MT/HA AT THE LACKAWANNA DEMONSTRATION PROJECT

Sludge Application	Year	Soil Depth	pH	Kjeldahl Nitrogen	Bray Phosphorus	K	Ca	Mg
mt/ha		cm		%	- - - - - - µg/g - - - - -			
80	1978[1]	0-15	3.8	0.22	15.75	31.2	256	15.6
		15-30	3.9	0.12	14.50	31.2	266	21.6
		30-60	3.8	0.12	9.00	39.0	296	24.0
		60-90	4.0	0.29	12.25	39.0	270	36.0
	1979	0-15	3.8	0.43	10.63	28.7	148	26.6
		15-30	3.5	0.00	11.20	33.4	44	12.1
	1982	0-15	5.9	0.30	21.78	29.9	1274	104.9
		15-30	4.3	0.21	12.00	25.3	362	72.7
108	1978	0-15	3.6	0.41	7.75	27.3	470	45.6
		15-30	3.7	0.25	9.50	27.3	446	48.0
		30-60	3.8	0.22	15.75	27.3	470	36.0
		60-90	3.9	0.26	9.75	35.1	380	30.0
	1979	0-15	3.6	0.47	8.70	24.2	620	49.7
		15-30	3.6	0.00	9.83	26.5	457	32.9
	1982	0-15	5.8	0.46	16.45	19.3	1100	104.3
		15-30	4.2	0.44	7.57	23.9	591	45.6

[1] 1978 values represent pretreatment conditions.

TABLE 59. CHANGES IN CONCENTRATIONS OF SOIL-EXTRACTABLE Fe, Al, AND Mn AT VARIOUS DEPTHS FOLLOWING SLUDGE APPLICATION AT 80 AND 108 MT/HA AT THE LACKAWANNA COUNTY DEMONSTRATION

Sludge Application	Year	Soil Depth	Fe	Al	Mn
mt/ha		cm		µg/g	
80	1978[1]	0-15	27.0	164	4.0
		15-30	26.5	178	4.5
		30-60	28.0	181	5.0
		60-90	29.5	183	5.0
	1979	0-15	17.0	194	5.3
		15-30	17.2	246	6.3
	1982	0-15	10.5	39	1.5
		15-30	32.0	85	8.1
		30-60	30.9	90	8.1
108	1978	0-15	31.5	145	7.0
		15-30	29.0	138	7.0
		30-60	26.5	138	6.5
		60-90	25.5	129	9.5
	1979	0-15	18.7	201	8.0
		15-30	17.9	208	11.5
	1982	0-15	24.2	50	2.3
		15-30	23.7	55	1.8
		30-60	23.3	55	1.7

[1] 1978 values represent pretreatment conditions

TABLE 60. CHANGES IN CONCENTRATIONS OF SOIL EXTRACTABLE TRACE METALS FOLLOWING SLUDGE APPLICATION AT 80 and 108 MT/HA AT THE LACKAWANNA DEMONSTRATION PROJECT

Sludge Application	Year	Soil Depth	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha		cm	- - - - - - - - - - µg/g - - - - - - - - - -						
80	1978[1]	0-15	7.13	1.13	<0.01	3.50	<0.01	0.005	0.25
		15-30	6.88	1.50	<0.01	1.75	<0.01	0.004	0.25
		30-60	6.75	1.25	<0.01	1.25	<0.01	0.004	0.13
		60-90	7.50	1.38	<0.01	0.75	<0.01	0.005	0.50
	1979	0-15	6.95	3.02	<0.01	0.62	0.23	0.003	0.13
		15-30	7.17	1.70	<0.01	0.47	0.23	0.006	0.53
	1982	0-15	18.38	22.87	1.00	9.02	0.57	0.419	1.30
		15-30	6.13	2.88	0.13	0.70	0.45	0.010	1.70
		30-60	5.92	1.67	0.08	0.60	0.33	0.009	0.95
108	1978	0-15	7.63	1.50	<0.01	1.13	0.38	0.009	0.50
		15-30	7.63	1.75	<0.01	0.88	0.38	0.009	0.63
		30-60	7.75	1.75	<0.01	1.00	0.25	0.006	0.38
		60-90	8.25	2.13	<0.01	0.75	0.38	0.009	0.63
	1979	0-15	7.85	3.77	0.05	0.90	0.35	0.003	0.97
		15-30	7.92	4.82	0.02	0.45	0.48	0.003	0.93
	1982	0-15	18.87	25.50	0.63	5.55	0.67	0.369	1.47
		15-30	8.42	5.55	0.17	2.92	0.33	0.010	0.67
		30-60	7.57	3.90	0.13	3.68	0.23	0.011	0.57
Normal Ranges in Soils (Allaway, 1968)			2-100	10-300	5-3000	2-200	1-40	0.01-7.00	5-500

[1] 1978 values represent pretreatment conditions.

are given in Table 7. Lead, Co, and Ni concentrations on the sludge-treated areas were all well below the maximum values reported for farmland soils. Concentrations of other trace metals were increased up to three fold over the maximum values.

Vegetation

Vegetation growth responses were evaluated at the end of each growing season. Measurements of vegetation heights were taken at 10 locations along each of two transect lines in each sludge treatment plot. Sampling points were spaced evenly along each transect line. The results of these measurements are given in Table 61. There was a complete vegetative cover on the sludge-treated areas by August 1978, two months after the sludge application. Average height growth was the greatest the second year and averaged 81.5 cm. The apparent decrease in height growth in the third and fourth year is due to the shift in the type of predominant cover from tall growing grass species to shorter legume species.

To determine dry matter production, twenty, 0.1 m^2 samples of the vegetative cover were collected in each of the sludge treatment plots. Four 0.1 m^2 samples of the vegetation were clipped along five transect lines in each area. The results are given in Table 61. Average dry matter production the first year ranged from 3.3 to 4.0 mt/ha with the highest average dry matter production found in the 80 mt/ha sludge treatment plot. In 1979, the average dry matter production was more than double that of the first year. Dry matter production reached a maximum in the third year and then decreased slightly in the fourth year.

Individual samples of each of the two grass and two legume species were collected from each sludge-treated area for foliar analyses. Foliar samples were prepared for analyses in the same manner as samples collected from the Venango County demonstration site.

At the end of each growing season individual samples of the two grass and two legume species were collected from each sludge-treated plot for foliar analyses. Results of these analyses are given in Tables 62 to 67. There was no significant difference in foliar concentrations between the two sludge application rates, except for Mn, which was consistently higher in plants grown with the higher rate of sludge (Tables 62, 64, and 66).

Results of the foliar analyses for concentrations of trace metals are given in Tables 63, 64, and 67. In general, there was little difference between foliar concentrations of any of the trace metals for the two sludge application rates. The legume species had slightly higher concentrations than the grass species. Results of the panic grass foliar analyses indicate that there was little difference in trace metal concentrations on the sludge-treated plots in comparison to the surrounding untreated area. In fact, trace metal concentrations of Zn, Cr, Cd, Pb, and Ni were higher in the foliage of the panic grass on the untreated area than on sludge-treated areas. In general, foliar concentrations decreased during the second growing season (1979) and between 1980 and 1981, there were marked decreases in foliar Cr, Pb, Co, Cd, and Ni. It should be noted that all trace metal concentrations

TABLE 61. VEGETATION HEIGHT GROWTH AND DRY MATTER PRODUCTION AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT.

Sludge Application	Height			
	1978	1979	1980	1981
mt/ha	cm			
80	35	82	46	36
108	47	81	53	38

Sludge Application	Dry Matter Production			
	1978	1979	1980	1981
mt/ha	mt/ha			
80	4.0	8.2	18.8	14.7
108	3.3	7.3	18.7	17.3

TABLE 62. MEAN CONCENTRATIONS OF SELECTED CONSTITUENTS IN VEGETATION FOLIAR SAMPLES COLLECTED AT THE END OF THE 1979 GROWING SEASON FROM THE LACKAWANNA COUNTY DEMONSTRATION PROJECT.

Sludge Application	N	P	K	Ca	Mg	Mn	Fe	B	Al
mt/ha			%				µg/g		
			Birdsfoot Trefoil						
80	3.60	0.28	1.49	1.92	0.49	69	93	48	25
108	3.52	0.25	1.38	1.86	0.56	95	105	52	32
			Crownvetch						
80	3.75	0.23	1.48	2.72	0.77	82	106	39	30
108	3.54	0.29	1.62	2.62	0.69	98	90	36	20
			Tall Fescue						
80	2.51	0.28	1.78	0.58	0.55	48	185	10	84
108	2.81	0.31	1.90	0.87	0.54	107	184	13	70
			Orchardgrass						
80	2.35	0.28	1.94	0.52	0.48	113	193	9	76
108	2.31	0.28	1.62	0.84	0.45	132	160	13	64
			Panic Grass						
0	1.48	0.43	1.73	0.22	0.27	135	685	7	363
80	2.23	0.44	1.58	0.63	0.67	56	90	8	18
108	2.49	0.35	1.80	0.71	0.70	85	114	8	30

TABLE 63. MEAN FOLIAR CONCENTRATIONS OF TRACE METALS IN SAMPLES COLLECTED IN 1979 FROM THE LACKAWANNA COUNTY DEMONSTRATION PROJECT

Sludge Application	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha				µg/g			
				Birdsfoot Trefoil			
80	11.8	49.2	0.5	5.7	0.6	0.04	4.7
100	11.6	50.0	0.3	6.0	0.7	0.05	4.8
				Crownvetch			
80	11.0	59.4	0.5	3.9	1.3	0.08	2.2
100	11.3	54.1	0.5	3.7	1.0	0.09	2.4
				Tall Fescue			
80	7.1	24.9	0.3	0.8	0.8	0.07	1.8
100	11.0	31.1	0.5	1.4	0.5	0.09	2.1
				Orchardgrass			
80	12.5	40.5	0.3	3.0	1.2	0.09	2.8
108	12.1	35.3	0.3	2.8	0.5	0.08	1.8
				Panic Grass			
0	11.3	41.8	0.4	5.0	0.2	0.07	2.7
80	16.3	34.7	0.2	1.0	0.3	0.05	1.9
108	20.5	44.3	0.2	2.3	0.2	0.06	1.8
Suggested*† Tolerance Level	150	300	2	10	5	3	50

*Melsted (1973)

†Council for Agricultural Science and Technology (1976).

TABLE 64. MEAN FOLIAR CONCENTRATIONS OF SELECTED CONSTITUENTS IN VEGETATION SAMPLES COLLECTED IN 1980 FROM THE LACKAWANNA COUNTY DEMONSTRATION PROJECT.

Sludge Application	N	P	K	Ca	Mg	Mn	Fe	B	Al
mt/ha	%					µg/g			
				Birdsfoot Trefoil					
80	2.61	0.18	1.33	1.64	0.44	43	67	32	39
108	2.57	0.20	1.43	1.69	0.41	50	72	36	39
				Crownvetch					
80	3.18	0.20	1.36	1.99	0.61	41	79	23	38
108	3.23	0.20	1.73	1.89	0.56	55	76	22	32
				Tall Fescue					
80	1.65	0.40	1.75	0.48	0.52	28	114	8	63
108	1.69	0.46	1.97	0.41	0.37	44	84	6	41
				Orchardgrass					
80	1.96	0.43	2.49	0.44	0.44	53	71	7	32
108	1.84	0.53	2.78	0.39	0.39	100	64	7	31

TABLE 65. MEAN FOLIAR CONCENTRATIONS OF TRACE METALS IN VEGETATION SAMPLES COLLECTED IN 1980 FROM THE LACKAWANNA COUNTY DEMONSTRATION PROJECT.

Sludge Application	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha	μg/g						
				Birdsfoot Trefoil			
80	6.3	32.0	0.3	3.9	3.3	0.04	4.4
108	6.8	35.4	0.3	2.4	2.4	0.16	4.3
				Crownvetch			
80	8.5	45.4	0.3	2.8	3.3	0.17	2.3
108	6.5	55.4	0.3	3.4	3.3	0.03	2.9
				Tall Fescue			
80	8.2	21.9	0.3	1.1	1.8	0.14	2.3
108	6.3	20.9	0.3	0.7	2.5	0.19	2.2
				Orchardgrass			
80	11.8	30.7	0.3	1.7	1.7	0.17	2.7
108	9.3	31.4	0.3	0.8	1.8	0.10	3.2
Suggested *† Tolerance Levels	150	300	2	10	5	3	50

* Melsted (1973).

† Council for Agricultural Science and Technology (1976).

TABLE 66. MEAN FOLIAR CONCENTRATIONS OF SELECTED CONSTITUENTS IN VEGETATION SAMPLES COLLECTED AT THE END OF THE 1981 GROWING SEASON FROM THE LACKAWANNA COUNTY DEMONSTRATION PROJECT.

Sludge Application	N	P	K	Ca	Mg	Mn	Fe	B	Al
mt/ha	%					µg/g			
Birdsfoot Trefoil									
80	3.34	0.19	1.21	2.34	0.42	51	217	57	107
108	3.30	0.18	1.12	1.77	0.48	108	72	45	48
Crownvetch									
80	3.28	0.17	1.25	2.35	0.57	87	87	28	46
108	3.57	0.20	1.37	2.04	0.65	104	95	29	45
Tall Fescue									
80	1.78	0.52	2.13	0.60	0.37	70	56	6	44
108	1.78	0.44	2.50	0.45	0.38	89	63	6	39
Orchardgrass									
80	2.26	0.54	2.78	0.53	0.37	66	62	6	32
108	1.56	0.53	2.51	0.48	0.37	132	73	7	39

TABLE 67. MEAN FOLIAR CONCENTRATIONS OF TRACE METALS IN VEGETATION SAMPLES COLLECTED AT THE END OF THE 1981 GROWING SEASON FROM THE LACKAWANNA COUNTY DEMONSTRATION PROJECT

Sludge Application	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha	µg/g						
				Birdsfoot Trefoil			
80	6.7	20.4	<0.1	2.7	0.7	0.53	1.2
108	7.0	51.3	<0.1	1.8	0.5	0.52	6.0
				Crownvetch			
80	6.5	45.8	<0.1	1.6	0.7	0.20	0.8
108	7.8	57.2	<0.1	1.3	0.7	0.49	0.8
				Tall Fescue			
80	7.9	22.4	<0.1	1.8	0.7	0.24	0.8
108	8.3	20.9	<0.1	0.4	0.5	0.49	0.6
				Orchardgrass			
80	11.7	32.7	<0.1	0.6	0.6	0.42	1.6
	9.3	22.7	<0.1	1.1	0.3	0.37	0.7
Suggested *,† Tolerance Levels	150	300	2	10	5	3	50

* Melsted (1973).

† Council for Agricultural Science and Technology (1976).

for all years (1978-1981) were well below the suggested tolerance levels and no phytotoxicity symptoms were observed.

Soil Percolate Water Quality

Results of the analyses for selected chemical constituents for percolate water collected at the 90-cm depth in 1980, 1981, and 1982 for both of the sludge-treated areas as well as the control area are given in Tables 68 to 73 and in Appendix Tables A-33 to A-35. Average concentrations of nitrate-nitrogen in all areas never approached the potable water standard of 10 mg/l following sludge application, with the highest value recorded for NO_3-N being 7.5 mg/l. Orthophosphate-P concentrations were only slightly increased by the sludge applications, and only in some cases. Results also indicate that the applications of lime and sludge had little effect on the pH of soil percolate water at the 90 cm depth during 1980-82. These findings were consistent with those for 1979, the first year after sludge application.

Concentrations of trace metals in the percolate on both sludge-treated plots were extremely low (Tables 71 to 73). There appears to be no significant increase in the concentrations of trace metals as a result of sludge applications to the anthracite refuse. Trace metal concentrations in soil percolate water decreased in the second year (1979) after sludge application with little change throughout 1980, 1981, and 1982, except for further decreases in Cu and Cd concentrations.

Copper concentrations in soil percolate water collected from sludge-treated plots were consistently within drinking water standards and below concentrations in control samples (Figure 10). While Cu concentrations from control plots fluctuated markedly between 1978 and 1982, those from sludge-treated plots showed a definite decrease over time.

Concentrations of all trace metals except Pb were within USEPA limits for potable water. In soil percolate water from both control and sludge-treated plots, Pb concentrations rarely exceeded drinking water standards, and then by negligible amounts, e.g., the highest Pb concentration between 1980 and 1982 on the sludge treated plots was 0.16 mg/l compared to the standard of 0.05 mg/l.

Separate samples of percolate water were collected from the lysimeters for total and fecal coliform analyses. No total or fecal coliform colonies (per 100 ml aliquots) were observed for any sample.

Groundwater Quality

Results of the analyses of groundwater well samples are given in Tables 74 to 79 and in Appendix Tables A-36 to A-38. Well 1 was drilled as a control, outside the area of influence of the sludge applications. Groundwater flow under the sludge-treated areas is toward Wells 2 and 3, therefore reflecting the effects of the sludge applications on groundwater quality. However, Wells 1 and 3 were vandalized in 1978, and only results for Well 2 are presented. For Well 2, depth to the water table ranged from 24.4 to 29 m between 1980 and 1982. Compared to the control well data from 1978, well

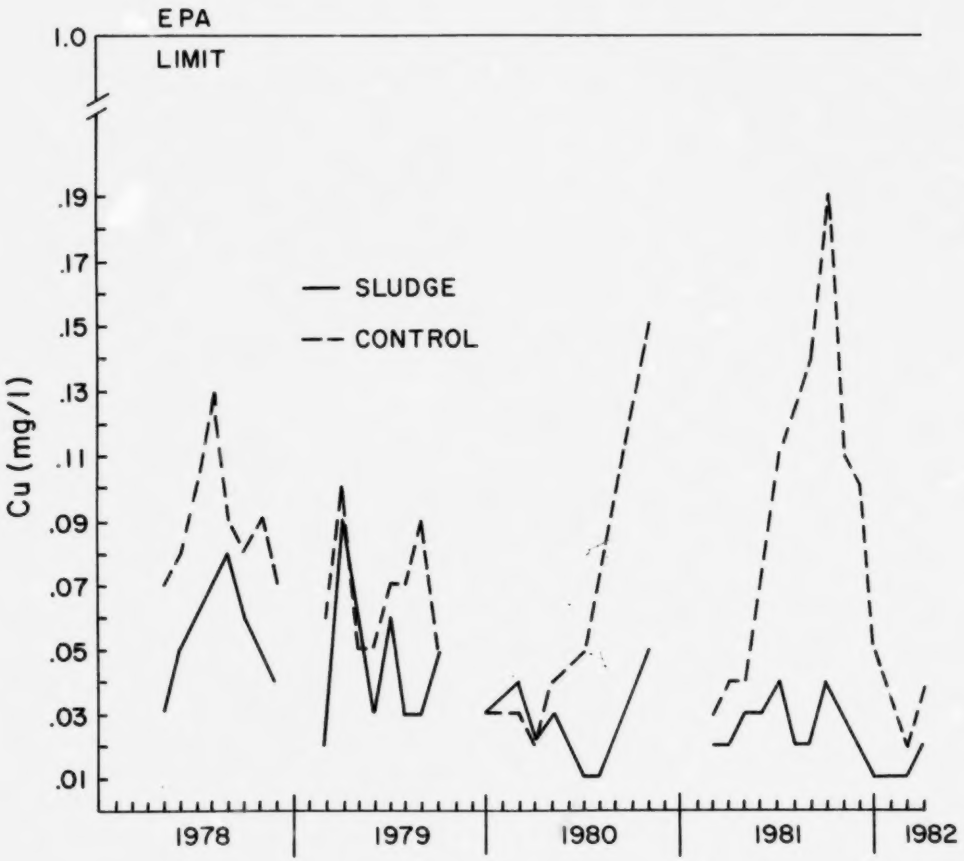

Figure 10. Copper concentrations in soil percolate water on the area treated with 108 mt/ha of dewatered sludge on the Lackawanna County demonstration plot.

TABLE 68. SOIL PERCOLATE ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1980.

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - - -		mg/l - - - -	- - - - - - - - - -	
0	Jan	.003	0.5	0.14	0.04	4.1
	March	.018	0.5	0.05	0.00	4.0
	April	.017	0.5	0.06	0.11	4.1
	May	.014	0.5	0.40	0.32	4.1
	July	.000	0.8	0.90	0.28	4.0
	Nov	.022	0.5	0.06	0.83	3.7
80	Jan	.017	0.5	0.14	0.05	4.4
	March	.016	0.6	0.36	0.00	4.5
	April	.022	0.5	0.19	0.29	4.7
	May	.016	0.8	0.45	0.32	4.6
	July	.024	1.7	2.14	0.50	5.1
	Aug	.082	1.0	0.68	0.00	3.8
	Nov	.054	1.0	0.05	0.27	4.7
108	Jan	.014	0.6	0.09	0.04	4.2
	March	.022	0.5	0.20	0.00	4.0
	April	.018	0.5	0.14	0.31	4.5
	May	.018	0.6	0.34	0.38	3.9
	July	.026	0.5	1.58	0.04	4.4
	Aug	.050	0.5	0.40	0.00	3.9
	Nov	.034	0.5	0.33	0.16	4.0

TABLE 69. SOIL PERCOLATE ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1981

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - - - -	- - - - - mg/l	- - - - -	- - - - - - - - - - -	
0	March	0.018	0.5	0.08	0.16	4.0
	April	0.018	0.5	0.16	0.24	3.8
	May	0.014	0.5	0.18	0.04	4.1
	June	0.027	0.5	0.53	0.33	3.6
	July	0.033	0.7	0.26	0.28	3.6
	Sep	0.004	0.5	0.05	0.51	3.6
	Oct	0.031	0.5	0.34	0.14	3.4
	Nov	0.011	0.5	0.24	0.00	3.4
	Dec	0.016	0.5	0.05	0.05	3.5
80	March	0.057	0.5	0.14	0.29	5.0
	April	0.037	1.3	0.20	0.27	4.6
	May	0.023	0.7	0.22	0.12	4.1
	June	0.063	7.6	0.54	0.44	4.6
	July	0.033	1.0	1.24	0.37	4.4
	Sep	--	1.8	0.27	--	4.0
	Oct	0.047	1.3	0.64	--	3.8
	Nov	0.048	0.5	0.40	0.02	3.4
	Dec	0.025	0.6	0.13	0.18	3.7
108	March	0.023	0.5	0.10	0.38	4.5
	April	0.027	0.5	0.23	0.20	4.3
	May	0.024	0.5	0.34	0.20	4.4
	June	0.047	0.5	0.57	0.41	4.1
	July	0.031	0.7	0.52	0.47	4.3
	Aug	0.020	0.5	0.05	0.00	6.9
	Sep	0.009	0.5	0.36	0.57	4.0
	Oct	0.034	0.7	0.78	0.15	3.6
	Nov	0.020	0.5	0.35	0.02	4.0
	Dec	0.012	0.5	0.07	0.20	4.0

TABLE 70. SOIL PERCOLATE ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1982.

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - - -		mg/l - - - - - - - - - - - - -		
0	Jan	0.013	0.5	0.07	0.03	3.4
	March	0.013	0.5	0.05	0.05	3.6
	April	0.006	0.7	0.16	0.32	3.8
80	Jan	0.028	1.2	0.12	0.24	4.0
	March	0.028	0.5	0.59	0.22	4.6
	April	0.021	1.0	0.64	0.29	4.3
108	Jan	0.016	0.8	0.08	0.09	4.3
	March	0.026	0.5	0.27	0.16	4.6
	April	0.014	0.5	0.45	0.22	4.4

TABLE 71. SOIL PERCOLATE ANALYSES FOR TRACE METALS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1980.

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha					mg/l			
0	Jan	0.03	0.33	0.01	0.03	0.04	0.001	0.10
	Mar	0.03	0.23	0.01	0.10	0.04	<0.001	0.07
	Apr	0.02	0.57	0.01	0.04	0.04	0.002	0.05
	May	0.04	0.48	0.01	0.01	0.02	<0.001	0.06
	Jul	0.05	0.62	0.01	0.01	0.01	<0.001	0.02
	Nov	0.15	0.75	0.01	0.05	0.07	0.002	0.19
80	Jan	0.02	0.31	0.01	0.01	0.05	0.001	0.10
	Mar	0.02	0.30	0.02	0.13	0.03	0.001	0.06
	Apr	0.02	0.42	0.01	0.03	0.05	0.001	0.05
	May	0.02	0.57	0.01	0.01	0.03	<0.001	0.05
	Jul	0.02	0.32	0.01	0.02	0.04	0.001	0.04
	Aug	0.10	2.10	0.01	0.03	0.10	0.004	0.17
	Nov	0.08	0.87	0.01	0.08	0.05	0.003	0.16
108	Jan	0.03	0.84	0.01	0.07	0.10	0.002	0.22
	Mar	0.04	1.37	0.02	0.16	0.13	0.001	0.32
	Apr	0.02	0.87	0.01	0.06	0.09	0.008	0.12
	May	0.03	0.75	0.01	0.03	0.06	0.001	0.16
	Jul	0.01	0.29	0.01	0.01	0.01	0.001	0.01
	Aug	0.01	0.39	0.01	0.06	0.01	0.001	0.01
	Nov	0.05	0.60	0.04	0.08	0.05	0.003	0.10
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 72. SOIL PERCOLATE ANALYSES FOR TRACE METALS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1981.

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha					mg/l			
0	Mar	0.03	0.20	0.01	0.07	0.03	0.001	0.05
	Apr	0.04	0.17	0.01	0.04	0.03	0.001	0.07
	May	0.04	0.40	0.01	0.01	0.02	0.003	0.04
	Jun	0.07	0.28	0.04	0.01	0.04	0.002	0.08
	Jul	0.11	0.54	0.04	0.01	0.03	0.005	0.08
	Sep	0.14	0.66	0.03	0.02	0.08	0.006	0.16
	Oct	0.19	0.89	0.01	0.01	0.07	0.003	0.25
	Nov	0.11	0.52	0.02	0.01	0.05	0.002	0.16
	Dec	0.10	0.43	0.01	0.01	0.03	0.001	0.14
80	Mar	0.02	0.14	0.01	0.03	0.02	<0.001	0.03
	Apr	0.03	0.19	0.01	0.09	0.03	0.001	0.05
	May	0.03	0.11	0.01	0.02	0.01	0.004	0.02
	Jun	0.04	0.15	0.04	0.01	0.01	0.005	0.04
	Jul	0.05	0.19	0.03	0.01	0.01	0.007	0.05
	Sep	0.11	0.70	0.03	0.01	0.06	0.003	0.22
	Oct	0.09	0.73	0.01	0.01	0.08	0.002	0.15
	Nov	0.07	0.43	0.01	0.06	0.04	0.001	0.10
	Dec	0.06	0.43	0.02	0.01	0.03	0.001	0.09
108	Mar	0.02	0.43	0.01	0.05	0.04	0.001	0.09
	Apr	0.02	0.29	0.01	0.01	0.04	0.001	0.10
	May	0.03	0.19	0.01	0.02	0.02	0.001	0.05
	Jun	0.03	0.22	0.04	0.01	0.02	0.004	0.07
	Jul	0.04	0.23	0.04	0.01	0.02	0.001	0.05
	Aug	0.02	0.21	0.04	0.01	0.01	0.010	0.01
	Sep	0.02	0.51	0.04	0.01	0.05	0.004	0.13
	Oct	0.04	0.68	0.01	0.01	0.04	0.003	0.13
	Nov	0.03	0.48	0.01	0.01	0.02	0.001	0.11
	Dec	0.02	0.52	0.01	0.01	0.02	0.001	0.11
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 73. SOIL PERCOLATE ANALYSES FOR TRACE METALS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1982

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha					mg/l			
0	Jan	0.05	0.40	0.01	0.01	0.05	0.001	0.10
	March	0.02	0.12	0.01	0.01	0.01	<0.001	0.01
	April	0.04	0.21	0.01	0.05	0.01	<0.001	0.05
80	Jan	0.02	0.39	0.01	0.03	0.04	0.001	0.07
	March	0.04	0.37	0.01	0.05	0.02	<0.001	0.06
	April	0.03	0.24	0.01	0.07	0.01	<0.001	0.03
108	Jan	0.01	0.37	0.01	0.04	0.04	0.001	0.08
	Mar	0.01	0.49	0.01	0.04	0.04	<0.001	0.15
	Apr	0.02	0.63	0.01	0.03	0.02	0.001	0.08
USEAP Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 74. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1980.

Well No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		mg/l				
Well 2 (treated) 1980	Jan	.017	0.5	0.87	0.23	6.8
	March	.082	0.5	0.15	0.00	7.3
	April	.018	1.0	0.55	0.56	6.9
	May	.029	0.5	0.65	0.77	7.8
	July	.001	0.5	0.82	1.30	7.9
	Aug	.026	2.4	0.53	0.22	6.6
	Sept	.031	0.5	0.48	0.00	7.4
	Nov	.003	0.5	0.05	0.00	7.5
Well 1 (control) 1978	July	0.025	<0.5	1.45	0.75	5.5
	Aug	0.021	<0.5	1.02	-	5.9
	Sept	0.005	<0.5	1.65	0.31	7.5

TABLE 75. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1981.

Well No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		mg/1				
Well 2 (treated)	March	.033	0.5	0.61	0.61	6.7
	April	.006	0.5	0.62	0.36	6.9
	May	.006	1.2	0.71	0.27	7.2
	June	.035	19.0*	0.59	0.00	5.8
	July	.048	0.5	0.73	0.94	7.9
	Aug	.005	0.5	0.71	0.16	6.3
	Sept	.001	0.5	0.36	0.49	6.2
	Oct	.019	1.8	0.75	0.10	7.9
	Nov	.020	8.8	1.05	0.00	6.1
	Dec	.013	5.3	0.48	0.21	6.9

* Problems with NO_3-N meter during May and June, 1981; meter was replaced in June.

TABLE 76. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1982.

Well No.	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
		mg/1				
Well 2	Jan	.040	4.2	0.69	0.70	7.7
	Feb	.008	0.5	0.65	0.70	7.6
	March	.030	1.8	0.75	0.20	5.6
	April	.001	3.1	0.58	0.65	5.8

TABLE 77. GROUNDWATER ANALYSES FOR TRACE METALS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1980.

Well No.	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
					mg/l			
Well 2 (Treated)	Jan	0.01	0.30	0.01	0.05	0.01	<0.001	0.02
	Mar	0.06	0.59	0.01	0.05	0.01	0.001	0.04
	Apr	0.18	1.53	0.02	0.01	0.03	0.002	0.07
	Mar	0.08	1.19	0.03	0.01	0.02	<0.001	0.04
	Jul	0.02	0.06	0.01	0.01	0.01	<0.001	0.01
	Aug	0.01	0.05	0.01	0.01	0.01	<0.001	0.01
	Sep	0.01	0.06	0.01	0.01	0.01	<0.001	0.01
	Nov	0.02	0.04	0.01	0.08	0.01	<0.001	0.01
Well 1 (Control) 1978	July	0.14	3.45	0.01	0.18	0.28	0.002	0.38
	Aug	0.15	1.03	0.05	0.20	0.22	<0.001	0.19
	Sept	0.37	0.59	0.01	0.16	0.05	0.003	0.10
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 78. GROUNDWATER ANALYSES FOR TRACE METALS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1981

Well No.	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
		- - - - - - - - - - - -			mg/l	- - - - - - - - - - - - - -		
Well 2	Mar	0.03	0.11	0.01	0.04	0.02	< 0.001	0.01
	Apr	0.04	0.04	0.01	0.07	0.01	< 0.001	0.01
	May	0.03	0.01	0.02	0.01	0.01	< 0.001	0.01
	Jun	0.08	0.03	0.04	0.01	0.02	< 0.001	0.01
	Jul	0.04	0.02	0.07	0.01	0.01	< 0.001	0.01
	Aug	0.03	0.02	0.03	0.01	0.01	< 0.001	0.01
	Sept	0.03	0.05	0.03	0.01	0.01	< 0.001	0.01
	Oct	0.01	0.07	0.01	0.01	0.01	< 0.001	0.01
	Nov	0.01	0.02	0.01	0.06	0.01	< 0.001	0.01
	Dec	0.01	0.06	0.03	0.01	0.01	< 0.001	0.03
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

TABLE 79. GROUNDWATER ANALYSES FOR TRACE METALS AT THE LACKAWANNA COUNTY DEMONSTRATION PROJECT DURING 1982

Well No.	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
		- - - - - - - - - - - -			mg/l	- - - - - - - - - - - - - -		
Well 2	Jan	0.02	0.24	0.03	0.01	0.01	<0.001	0.01
	Feb	0.01	0.06	0.01	0.07	0.01	<0.001	0.02
	Mar	0.01	0.04	0.01	0.01	0.01	<0.001	0.01
	Apr	0.01	0.09	0.01	0.06	0.01	<0.001	0.01
USEPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0*	0.01	2.0*

*Limits for irrigation water for agricultural land. No criteria set for drinking water.

water from sludge-treated plots had slightly higher ortho-P and NO_3-N concentrations, and lower NH^+_4-N concentrations in 1980-82. However, the increases in P and NO_3-N were negligible, and NO_3-N concentrations were within the USEPA drinking water standard. For all years following sludge application, all concentrations of trace metals in groundwater were within USEPA limits for potable water except Pb which exceeded the limits occasionally by insignificant amounts (highest Pb concentrations was 0.08 mg/l vs. the 0.05 mg/l limit).

SECTION 7

PRODUCTION AND QUALITY OF FORAGE VEGETATION

To evaluate the effect of sludge applications on mined land on the production and quality of forage vegetation, the results of this project were combined with several other projects which used the same type of sludge but at different application rates. A total of five demonstration areas were selected with a total of eight different sludge application rates. A description of the sites, sludge source and type, application rate, and years of data are given in Table 80.

The five demonstration sites included both bituminous and anthracite spoils, with and without topsoil. Sludges were obtained from several municipal treatment plants. Application rates ranged from 11 to 202 dry mt/ha, and vegetation was analyzed over periods of 2-5 years, depending on the site. Control vegetation adjacent to sludged sites received only the conventional fertilizer and lime applications. Due to a lack of control plants, means for controls over all sites were used for comparison with sludge-grown plants.

At each site after contouring and surface scarification, lime was applied to raise the pH to 7.0. Lime and either dewatered or liquid sludge were incorporated to 10 cm with either disc or chisel plow. Broadcast seeding mixture included orchardgrass (Dactylis glomerata L. 'Pennlate'), tall fescue (Festuca arundinacea Schreb. 'Kentucky-31'), and birdsfoot trefoil (Lotus corniculatus L. 'Empire'), with crownvetch (Coronilla varia L.) on some sites.

Vegetation for elemental analysis was sampled along transect lines on each plot at the end of each growing season (late August). Grasses were clipped at soil level, and trefoil approximately 20 cm from the growing tip. Foliar samples were analyzed after ashing and digestion for Kjeldahl-N, P, K, Ca, Mg, Mn, Fe, Al by plasma emission spectroscopy; and for Zn, Cu, Co, Ni, Pb, Cr, and Cd by atomic absorption. Vegetation was not harvested at any time. For yield determinations, ten 0.10 square meter samples were collected along transect lines on each site.

ELEMENTAL ANALYSES

Essential Plant Nutrients

Sludges usually contain sufficient plant nutrients to produce a marked growth response in crops, with most of the N being in a slowly available organic form. Because sludge was applied only once on the sites in this study, relatively high levels of nutrients were applied in order to meet crop

TABLE 80. DESCRIPTION OF THE FIVE STRIP MINE SITES IN PENNSYLVANIA THAT WERE RECLAIMED WITH MUNICIPAL SEWAGE SLUDGE.

County	Spoil Type	Sludge Source	Sludge Treatment	Application Rates (mt/ha)	Years of Data
Venango	abandoned bituminous	Farrell Franklin Oil City	activated sludge/anaerobic digestion liquid or dewatered	0,11,90,184	5
Lackawanna	anthracite refuse	Scranton	activated sludge dewatered	80,108	4
Westmoreland	abandoned bituminous	Philadelphia	anaerobic digestion dewatered 1:1 composted to non-composted	0,134	2
Somerset	topsoiled bituminous	Philadelphia	anaerobic digestion dewatered composted	0,202	4
Clarion	abandoned bituminous	Philadelphia	anaerobic digestion dewatered 1:1 composted to non-composted	128	3

needs for the 5-year period during which a self-maintaining vegetative cover is required to comply with PDER reclamation regulations. For the following discussions, foliar concentrations for all sites for the third growing season after sludge application (except Westmoreland which had only two growing seasons) were used (Table 81).

Ranges in plant nutrients applied on the sites (kg/ha) were: 284-2388 N, 66-1302 P, 5-246 K, 445-8522 Ca, 75-960 Mg, 9-300 Mn, 261-5390 Fe, 21-342 Zn, 21-148 Cu, and 0.2-3 Co. Compared to controls, which received conventional lime and fertilizer applications, the N, P, K, and Mg concentrations of sludge-grown plants were generally higher, with one exception, i.e., sludge-grown trefoil was lower in K and Mg than controls. Sludge-applied Ca appeared to increase trefoil Ca compared to controls, but had little effect on the grasses. Since Ca loadings in sludge were far greater than Mg and K loadings, and since dicotyledonous plants tend to concentrate Ca more than grasses, it is reasonable that foliar Ca, was increased in the trefoil by sludge applications. Birdsfoot trefoil had higher foliar N, as expected for a legume; while the grasses had higher foliar P than the trefoil.

Copper in sludge-grown plants was consistently within 5 ppm of control concentrations. Copper can accumulate in plants, but application of sludges at moderate rates results in only slight to moderate increases in Cu content of plants, as shown in this study. Under good management it is unlikely that Cu in sludges would be toxic to plants. Copper concentrations were consistently within the average range for agronomic crops (Council for Agricultural Science and Technology, 1976; Chapman, 1966; and University of Georgia Cooperative Extension Service, 1979).

Zinc was higher in sludge-grown plants than in controls, and may be a limiting factor in the loading rates of sludge applied to land. However, the increases in leaf-Zn were not higher than 85 ppm, and Zn concentrations of sludge-treated plants were consistently within the average range. Zinc in sludges may substantially increase foliar Zn, but plant toxicity rarely occurs. In this study the highest rate of Zn applied was 342 kg/ha. Murphy and Walsh showed that applications as high as 1390 kg/ha Zn had little or no effect on the growth of a variety of crops (Council for Agricultural Science and Technology, 1976).

Iron was consistently lower in sludge-grown plants than controls, and within the average range. Manganese concentrations of sludge-grown and control plants were similar. Mn levels of controls were higher than average, while in many cases sludge-grown plants had Mn levels within the average range. Except for orchardgrass on three sites, Mn concentrations were below food-chain tolerance levels. Table 82 defines and lists suggested tolerance levels for trace metals in agronomic crops. Iron, Mn, and Al are often taken up by plants in toxic amounts in eastern U.S. strip mine spoils. Uptake of Fe, Mn, and Al was decreased by sludge application, so aluminum, though not an essential element, is mentioned here. Manganese, Fe, and Al pose little hazard to crop production and plant accumulation when sludge is applied to soil because of their low solubility in slightly acid or neutral, well-aerated soils. Little uptake by plants occurs due to the low availability, so Fe and Al will not be a problem under good management.

TABLE 81. MEAN FOLIAR CONCENTRATIONS OF THE 2 GRASSES (ORCHARDGRASS AND TALL FESCUE) AND LEGUME (BIRDSFOOT TREFOIL) THE THIRD YEAR AFTER ELEMENTS WERE APPLIED AT VARIOUS RATES (KG/HA) IN SEWAGE SLUDGE.

kg/ha applied N		*0*	*284*	*726*	*968*	*1165*	*1241*	*1437*	*1691*	*2388*
% N	grasses	1.2	1.4	2.1	2.1	1.3	1.8	1.5	1.8	1.3
	legume	2.6	2.8	3.3	3.7	3.4	2.6	2.0	2.6	3.6
kg/ha applied P		*0*	*66*	*328*	*414*	*451*	*464*	*776*	*839*	*1302*
% P	grasses	0.19	0.46	0.42	0.45	0.50	0.39	0.43	0.46	0.29
	legume	0.18	0.17	0.18	0.23	0.20	0.25	0.30	0.25	0.11
kg/ha applied K		*0*	*5*	*8*	*17*	*101*	*139*	*176*	*181*	*246*
% K	grasses	1.8	2.4	2.5	2.4	2.1	2.4	2.7	2.9	2.1
	legume	1.9	1.5	1.4	1.6	1.3	1.4	2.0	1.5	0.77
kg/ha applied Ca		*0*	*445*	*893*	*1809*	*1816*	*1915*	*2926*	*6214*	*8522*
% Ca	grasses	0.42	0.56	0.53	0.51	0.27	0.44	0.51	0.46	0.40
	legume	1.1	1.6	1.5	1.5	0.25	1.2	1.5	1.6	1.7
kg/ha applied Mg		*0*	*75*	*187*	*370*	*378*	*485*	*507*	*692*	*960*
% Mg	grasses	0.21	0.25	0.28	0.48	0.27	0.20	0.38	0.39	0.24
	legume	0.27	0.22	0.23	0.44	0.20	0.06	0.41	0.33	0.18
kg/ha applied Mn		*0*	*9*	*110*	*112*	*121*	*131*	*148*	*153*	*300*
μg/g Mn	grasses	279	90	274	41	188	146	298	72	351
	legume	222	66	28	43	244	121	132	50	127
kg/ha applied Fe		*0*	*261*	*319*	*2501*	*2662*	*3389*	*3430*	*3794*	*5390*
μg/g Fe	grasses	445	79	78	93	64	97	74	53	53
	legume	199	95	105	67	110	95	72	25	98
kg/ha applied Al		*0*	*219*	*514*	*550*	*704*	*1113*	*1325*	*1673*	*2103*
μg/g Al	grasses	304	35	48	31	36	29	48	65	30
	legume	137	34	39	35	39	29	41	48	11

(Continued)

TABLE 81. (Continued)

kg/ha applied Zn	*0*	*21*	*64*	*72*	*86*	*147*	*183*	*245*	*342*
μg/g Zn grasses	21	25	27	35	26	65	62	37	50
legume	29	33	32	46	35	42	114	43	63
kg/ha applied Cu	*0*	*21*	*63*	*67*	*76*	*92*	*129*	*131*	*148*
μg/g Cu grasses	9.1	7.3	7.5	10.0	11.8	7.8	8.8	11.4	10.9
legume	8.4	8.3	8.9	6.3	10.6	6.8	9.2	8.9	9.8
kg/ha applied Cr	*0*	*16*	*16*	*21*	*36*	*40*	*42*	*42*	*74*
μg/g Cr grasses	2.3	7.7	0.25	0.25	11.6	0.25	<0.01	<0.01	2.5
legume	1.5	1.0	0.33	0.33	8.3	0.75	<0.01	<0.01	1.7
kg/ha applied Co	*0*	*0.2*	*0.4*	*0.8*	*0.9*	*1.1*	*2.0*	*2.2*	*3.0*
μg/g Co grasses	1.5	0.42	0.04	1.7	0.13	2.2	1.2	1.1	0.42
legume	1.7	0.75	1.3	3.3	<0.01	2.4	0.42	1.7	0.25
kg/ha applied Pb	*0*	*10*	*27*	*49*	*55*	*59*	*67*	*80*	*131*
μg/g Pb grasses	2.6	3.2	2.5	1.4	2.7	1.5	0.71	1.5	1.5
legume	3.7	3.3	1.8	3.9	1.8	3.3	2.4	2.0	2.2
kg/ha applied Ni	*0*	*1*	*4*	*6*	*7*	*8*	*12*	*13*	*30*
μg/g Ni grasses	5.3	10.9	2.5	2.7	16.0	1.6	5.3	1.4	4.5
legume	7.8	4.5	4.4	4.3	15.2	1.3	6.3	4.4	6.0
kg/ha applied Cd	*0*	*0.1*	*0.2*	*0.2*	*0.6*	*0.6*	*1.2*	*1.7*	*5.0*
μg/g Cd grasses	0.27	0.06	0.12	0.44	0.14	1.1	0.16	0.15	1.3
legume	0.23	0.03	0.11	0.57	0.04	1.3	0.04	0.16	1.4

Cobalt is essential for N-fixing bacteria, and thus for leguminous crops. Co concentrations of sludge-grown plants varied from controls by less than 2 ppm and were always below the suggested food-chain tolerance levels. The Co levels of control plants were above average, while in many cases sludge-grown plants had Co levels within the average range. The data indicate that the sludges supplied adequate, but not excessive, amounts of these essential micronutrients to the crop.

TABLE 82. SUGGESTED PERMISSIBLE TOLERANCE LEVELS OF TRACE METALS IN AGRONOMIC CROPS (Council for Agricultural Science and Technology, 1976; Melsted, 1973; and University of Georgia Cooperative Extension Service, 1979).

Element	Suggested Tolerance Level*
	------------ppm----------
Fe	750
Mn	300
Al	200
Zn	300
Cu	150
Cr	2
Pb	10
Co	5
Ni	50
Cd	3

*It is assumed that the tolerance levels include an acceptble safety factor, and are one-half, or less, of the values the literature suggests as being a) toxic to animals or plants and b) high enough for appreciable transfer of the element from leaves to grain.

Non-essential Trace Metals in Plants

The ranges for the non-essential metals applied in this study (kg/ha) were: 10-131 Pb, 1-30 Ni, 16-74 Cr, 0.1-5.0 Cd, and 219-2103 Al. Sludge-applied lead had little effect on foliar Pb concentrations. Lead in sludge-grown plants fluctuated above and below Pb values for controls, but never exceeded controls by more than 20 μg/g, and was consistently within the average range for agronomic crops. Several other studies showed that there was little change in Pb content of leaves when sewage sludge was incorporated in soil. Lead poses little hazard to crops because it is usually tied up by the high amounts of phosphate in the sludge (Chaney, 1973), and soil Pb would probably have to reach 10,000 μg/g for significant effects on plant growth to occur (Council for Agricultural Science and Technology, 1976).

Nickel and chromium concentrations in sludge-grown plants were generally the same as or lower than controls. Where Ni and Cr concentrations were higher than controls the third year, they dropped below control values the fourth year. Nickel and Cr in sludge-grown plants never exceeded controls by more than 15 µg/g, and were consistently below suggested food-chain tolerance levels. Chromium is accumulated very little by plants, and is not considered potentially toxic because it occurs as Cr^{+3} in sludge, which is not plant-available (Chaney, 1973). It has been reported that even 530 kg/ha applied Cr did not increase Cr concentration of corn leaves. The highest rate applied on the strip mine sites was 74 kg/ha. Nickel is considered more toxic to plants than Cu and Zn, but must be added in very high amounts to be toxic, and Ni toxicity has only been observed in acid soils (Council for Agricultural Science and Technology, 1976). Although it has been reported that Ni uptake may be increased by the presence of sludge organic matter, the data presented here show a marked decline in mean plant Ni concentrations over a 5-year period (Figure 11).

Cadmium in sludge-grown plants was lower than controls, and within the average range for this element on five out of eight sites. On the other three sites, Cd was below suggested food-chain tolerance levels. Several studies indicated that at rates of 2-29 kg/ha/yr Cd, most of the metal was converted to forms unavailable to the plant (Council for Agricultural Science and Technology, 1976). The highest Cd application on the strip mine sites was 5 kg/ha. Zinc may prevent Cd absorption by plants. The USDA has suggested a maximum Cd:Zn ratio of 0.5% for land application. Four of the six sludges used on the strip mine sites had Cd:Zn ratios below the suggested maximum. Of the other two, the maximum ratio was 2.1%.

Essential Animal Nutrients

Concentrations of K, Ca, Mg, Mn, Fe, and Co, essential in animal diets, were near or above minimum suggested for total dairy rations, which includes forage plus feed concentrates. Phosphorus, Cu, and Zn were below these levels in forage, but would routinely be subsidized in concentrates. Although Cr sometimes was above the suggested food-chain tolerance level the third year, it was consistently below this level the fourth year.

A wide safety margin exists between normal Zn dietary levels and levels which are toxic to animals, the same is true of Cr (Allaway, 1968). Allaway (1968) has reported a general decline in Zn concentrations of feed crops. The main issue with Cu is not its effect on animals, but its potential toxicity to plants if applied in large quantities over several years. Copper, Zn, and Ni will cause severe plant injury before the content of these elements is high enough to be toxic to most animals. Zinc and Cu concentrations were below suggested food-chain tolerance levels on all sites.

Non-essential Trace Metals in Animals

Concentrations of trace metals not required in animal diets, Pb, Ni, Cd, and Al were always below food-chain tolerance levels. Lead accumulates little in plant tissue, so even though the metal is toxic to animals, there is little

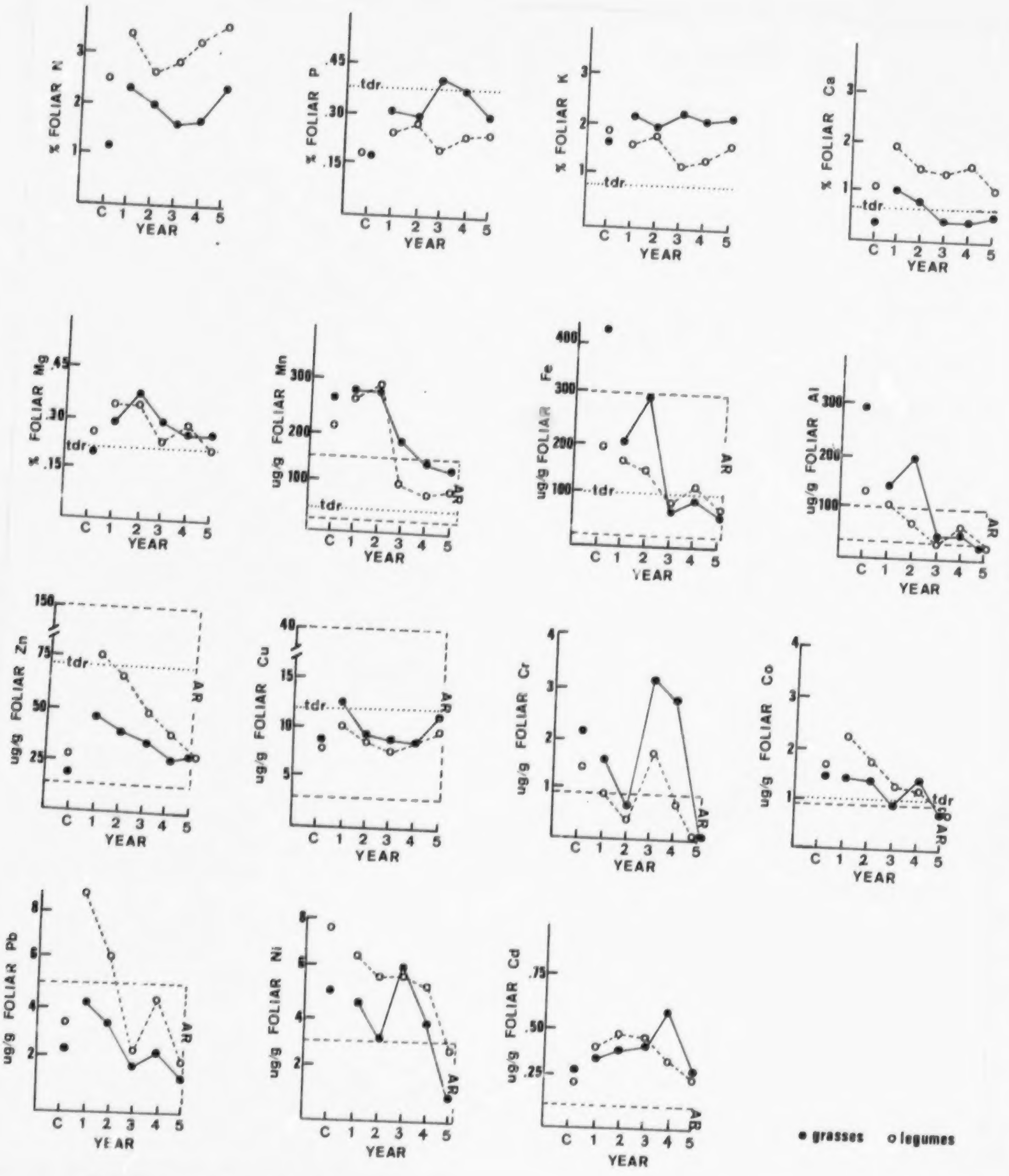

Figure 11. Mean foliar concentrations of grasses (tall fescue and orchardgrass) and birdsfoot trefoil (legume) for two to five years after sludge application, depending on the site. AR = average range.[4,9,11] tdr = minimum required in total dairy ration.[11]

potential for toxicity to grazing animals consuming sludge-fertilized forage. Cadmium concentrations on 5 of 8 sites were within average ranges. It is believed that a low Cd:Zn ratio in sludges will result in crop injury from Zn excess before plant tissue Cd could reach levels harmful to the food chain.

Five-Year Trends

When mean foliar concentrations over all sites were examined over a five-year period (Figure 11), concentrations of N, P, K, and Cu remained relatively constant. There was a slight decrease in Ca, Mg, and Cd concentrations, and a marked decrease in concentrations of Mn, Fe, Al, Zn, Cr, Co, Pb, and Ni. By the fifth year, all metals except Cd were within average ranges for agronomic crops. Although Cd exceeded the average range it was well below the tolerance level. It should be noted that on individual sites for certain elements and species, there were exceptions to these general trends.

Yields

Dry matter production expressed as hay yield in mt/ha was consistently higher on the sludge-amended strip mine sites than on undisturbed farmland in the same counties (Pennsylvania Crop Reporting Service, 1980), even for as many as five years after the initial sludge application (Figure 12). All sites had a complete vegetative cover within the first growing season, which persisted through the current growing season (1982), without harvest or cutting. Yields increased consistently each year.

Protein and Fiber

Crude protein (Figure 13) equalled or exceeded the minimum suggested for total dairy rations, 14%, and the average Pennsylvania values for forage grasses and legumes (Pennsylvania State University, 1970). Protein was higher than U.S. averages for fescues and trefoil (based on Medicago Lupulina), and close to U.S. averages for orchardgrass (Morrison, 1936).

Acid detergent fiber (ADF) (Figure 14) exceeded the minimum for total dairy rations, 18% (Pennsylvania State University, 1970). While fiber concentrations of grasses and legumes were below average Pennsylvania values, they were close to U.S. averages (Morrison, 1936).

Profits from pasture land depend on the efficiency of forage production. High protein content is indicative of high energy value and thus, high quality and efficiency. High protein content is desirable from a nutritional as well as an economic standpoint. Higher protein content in forage means lower amounts of feed concentrates needed to supplement protein. As the percent protein increases, percent fiber decreases.

Summary

Plant nutrients from sludges were sufficient to produce high yields of grasses and legumes. Concentrations of Fe, Al, Zn, Cu, Co, Pb, Ni, and Cd were below food-chain tolerance levels on all sites by the third year after

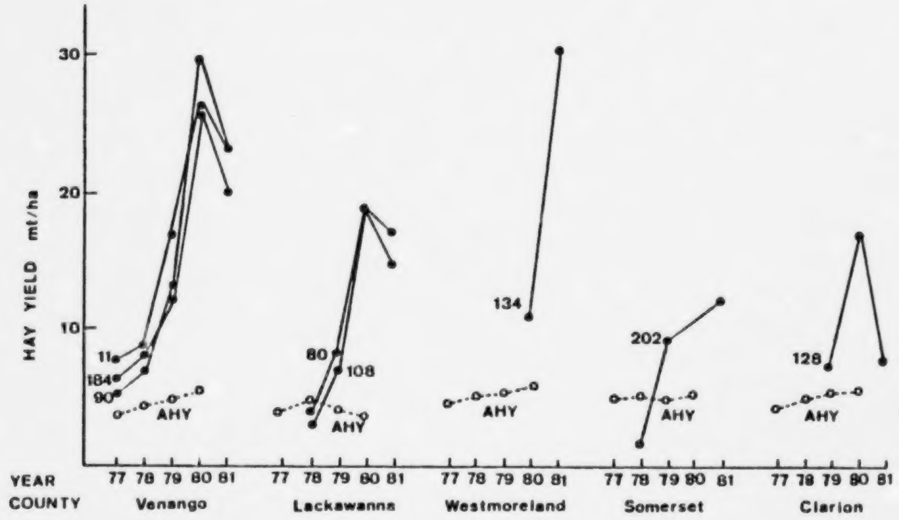

Figure 12. Hay yields (1977-1981) on strip mine sites reclaimed with sludge at various application rates (mt/ha) compared to average hay yields (AHY) in five counties (Pennsylvania Crop Reporting Service, 1980).

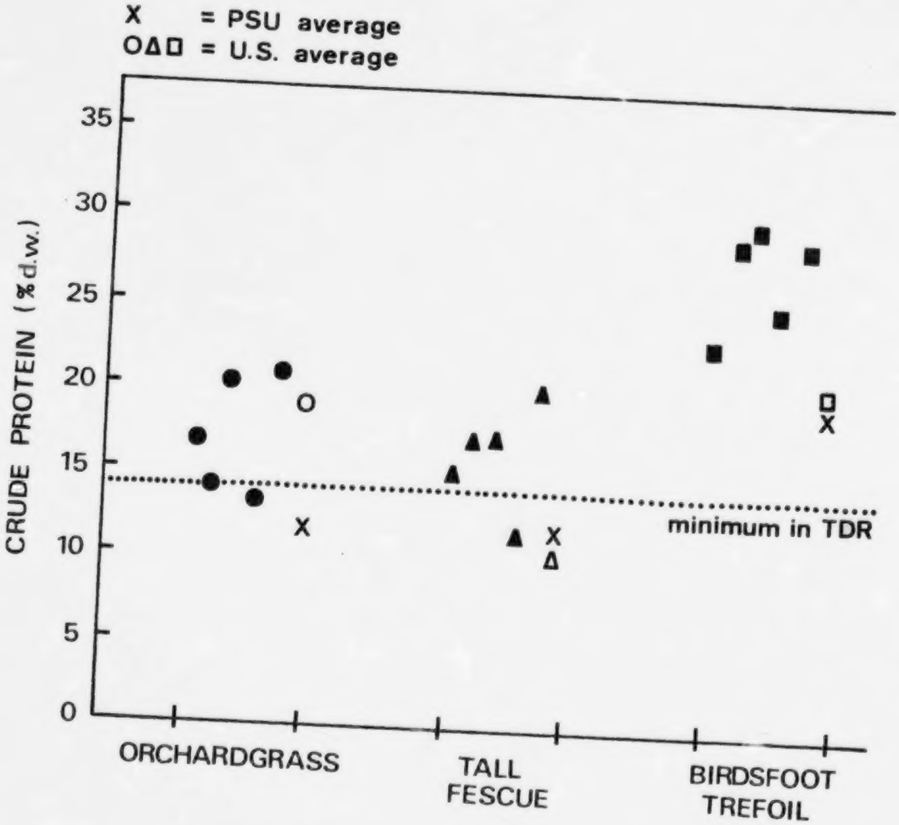

Figure 13. Crude protein concentration of forage species on strip mine sites reclaimed with sludge in five counties, compared to U.S. average (Morrison, 1936) and Pennsylvania average (Pennsylvania Crop Reporting Service, 1980). Minimum in TDR = total dairy ration (Pennsylvania Crop Reporting Service, 1980).

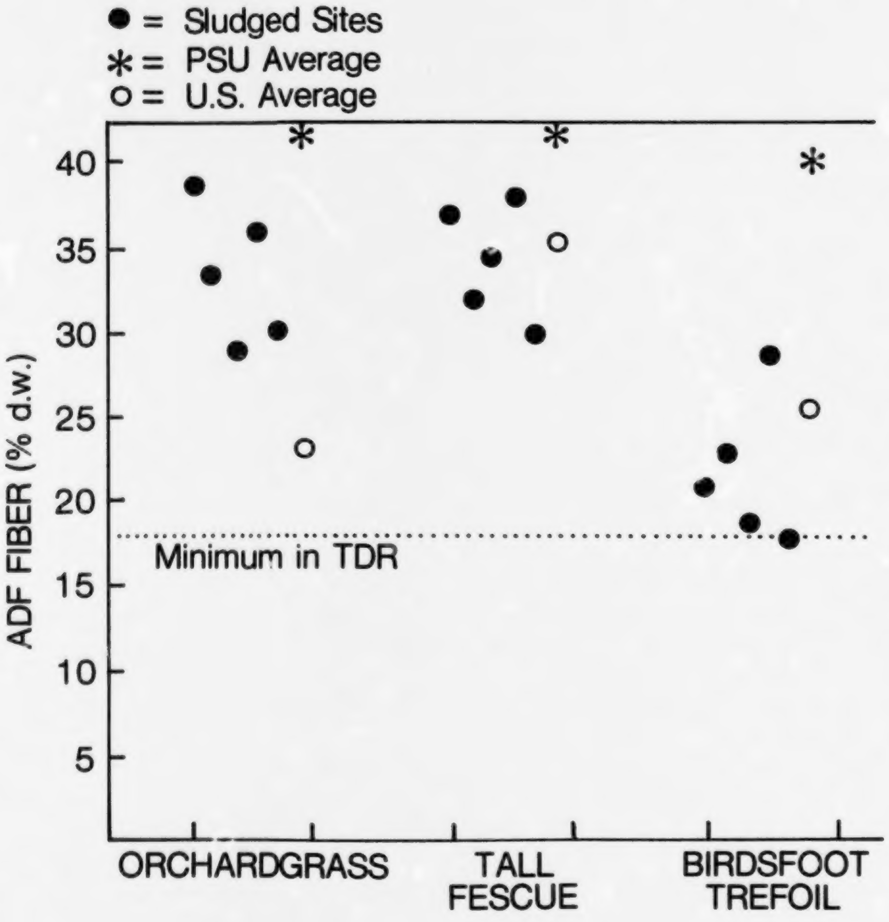

Figure 14. Fiber (acid detergent) concentration of forage species on strip mine sites reclaimed with sludge in five counties compared to U.S. average (Morrison, 1936) and Pennsylvania average (Pennsylvania Crop Reporting Service, 1980). Minimum in TDR - total dairy ration (Pennsylvania Crop Reporting Service, 1980).

sludge application. By the fifth year, mean metal concentrations over all sites were within normal ranges for agronomic crops, except for Cd which exceeded the normal range but which was still below the tolerance level. Protein and fiber contents were consistent with or better than average values for grasses and legumes.

By using good quality sludges low in trace metals and with sufficient plant nutrients, and retaining soil pH at 6.5 or above, strip mined land can be successfully reclaimed with forage species of such quality that any potential risks to plant or animal health are minimal. In addition, the high yields of vegetation obtained make reclamation with sewage sludge an economically feasible option.

APPENDIX

SUPPLEMENTAL TABLES

TABLE A-1. ANALYSES OF SOIL SAMPLES COLLECTED ON THE VENANGO COUNTY DEMONSTRATION PROJECT FOR KJELDAHL NITROGEN, BRAY PHOSPHORUS, AND EXCHANGEABLE CATIONS FOR 1979 AND 1981.

Sludge Application	Year	Soil Depth	pH	Kjeldahl Nitrogen	Bray Phosphorus	K	Ca	Mg
mt/ha		cm		%	- - - - - -	μg/g	- - - - - -	
7	1979	0 - 15	-	0.03	3.80	37	3847	54
		15 - 30	-	0.03	3.13	34	2832	74
11-L		0 - 15	7.3	0.08	2.72	47	4933	40
		15 - 30	6.1	0.06	2.28	30	4525	33
90-L		0 - 15	7.7	0.12	19.27	48	4900	94
		15 - 30	6.3	0.05	3.98	37	3712	60
184-L		0 - 15	7.3	0.16	38.17	46	3873	53
		15 - 30	5.1	0.05	11.78	31	853	31
0	1981	0 - 15	3.6	0.05	0.92	22	309	28
		15 - 30	3.1	0.05	0.33	16	263	37
7		0 - 15	5.4	0.05	1.67	29	941	38
		15 - 30	5.3	0.04	2.65	20	1355	41
11-L		0 - 15	5.3	0.09	5.83	24	1985	25
		15 - 30	3.6	0.05	2.18	12	1379	24
90-L		0 - 15	4.4	0.07	33.92	23	1444	53
		15 - 30	3.7	0.06	1.37	14	965	69
184-L		0 - 15	4.6	0.34	179.25	45	1298	99
		15 - 30	3.4	0.05	3.77	28	144	31

TABLE A-2. ANALYSES OF SOIL SAMPLES COLLECTED ON THE VENANGO COUNTY DEMONSTRATION PROJECT FOR SOIL EXTRACTABLE TRACE METALS FOR 1979 AND 1981.

Sludge Application	Year	Soil Depth	Cu	Zn	Cr	Pb	Co	Cd	Ni
		cm	μg/g						
7	1979	0 - 15	4.47	5.03	0.15	2.55	0.78	0.005	0.88
		15 - 30	3.58	4.75	0.10	2.53	0.78	0.005	1.07
11-L		0 - 15	1.77	2.52	0.12	1.90	0.60	0.043	0.38
		15 - 30	1.73	6.05	0.13	1.63	0.67	0.006	1.02
90-L		0 - 15	32.80	22.47	1.00	7.03	1.40	0.173	1.77
		15 - 30	6.73	5.05	0.28	3.18	0.32	0.014	0.35
184-L		0 - 15	58.72	56.90	1.72	12.97	1.20	0.268	1.52
		15 - 30	9.22	8.67	0.28	2.43	0.42	0.026	0.23
0	1981	0 - 15	0.53	0.52	0.02	1.37	0.15	0.006	0.42
		15 - 30	0.60	5.10	0.02	0.27	0.15	0.002	0.35
7		0 - 15	2.30	2.67	0.10	5.67	0.83	0.028	0.83
		15 - 30	1.60	1.85	0.03	2.02	0.73	0.015	0.68
11-L		0 - 15	3.68	6.40	0.33	2.28	1.47	0.132	1.14
		15 - 30	1.07	1.35	0.07	0.38	0.42	0.004	0.67
90-L		0 - 15	1.38	1.88	0.08	0.13	0.35	0.092	0.40
		15 - 30	2.37	2.58	0.25	0.97	0.65	0.035	0.73
184-L		0 - 15	87.3	74.6	3.50	22.70	1.60	0.950	2.80
		15 - 30	2.43	2.82	0.05	0.53	0.20	0.014	0.38

TABLE A-3. ANALYSES OF SOIL SAMPLES COLLECTED ON THE VENANGO COUNTY DEMONSTRATION PROJECT FOR SOIL EXTRACTABLE Fe, Al, AND Mn FOR 1979 AND 1981.

Sludge Application	Year	Soil Depth	Fe	Al	Mn
			- - - - - μg/g	- - - - - -	
7	1979	0 - 15	16.3	9.4	3.1
		15 - 30	16.1	8.9	3.1
11-L		0 - 15	15.1	5.7	2.6
		15 - 30	15.1	19.9	3.9
90-L		0 - 15	17.2	6.3	3.1
		15 - 30	17.0	14.1	6.1
184-L		0 - 15	15.8	4.6	2.9
		15 - 30	15.9	42.4	8.3
0	1981	0 - 15	9.6	67.5	6.3
		15 - 30	14.0	94.6	6.1
7		0 - 15	2.2	7.0	6.1
		15 - 30	12.1	21.7	2.2
11-L		0 - 15	4.2	15.3	3.2
		15 - 30	16.6	48.4	6.4
90-L		0 - 15	22.6	91.5	3.3
		15 - 30	73.4	89.0	5.3
184-L		0 - 15	16.2	77.8	27.3
		15 - 30	17.0	103.1	6.5

TABLE A-4. MEAN FOLIAR CONCENTRATIONS OF SELECTED CONSTITUENTS IN SAMPLES COLLECTED IN 1979 FROM THE VENANGO DEMONSTRATION PROJECT.

Species	Sludge Application	N	P	K	Ca	Mg	Mn	Fe	B	Al
				%				μg/g		
Birdsfoot Trefoil	0	2.59	0.14	1.74	1.82	0.40	150	113	41	36
	7	3.59	0.21	1.59	1.46	0.20	69	110	28	30
	11-L	2.81	0.17	1.47	1.63	0.22	66	105	31	34
	90-L	3.41	0.23	1.41	1.53	0.23	132	110	33	35
	184	3.83	0.24	1.90	1.60	0.41	433	133	46	48
	184-L	3.57	0.25	1.56	1.54	0.20	127	98	36	29
Crownvetch	7	2.89	0.17	1.30	2.08	0.23	67	94	17	32
	11-L	2.44	0.18	1.37	1.87	0.24	58	88	21	30
	90-L	2.69	0.19	1.08	1.59	0.28	83	113	19	38
	184	4.05	0.28	1.86	1.48	0.27	227	158	28	37
	184-L	3.35	0.22	1.29	1.68	0.25	130	124	27	33
Tall Fescue	0	1.01	0.18	1.68	0.40	0.26	209	185	8	123
	7	1.27	0.29	1.99	0.56	0.24	83	86	9	45
	11-L	1.15	0.44	2.10	0.56	0.26	56	76	7	35
	90-L	1.11	0.37	2.19	0.51	0.31	176	66	8	35
	184	1.30	0.43	1.89	0.47	0.34	586	84	9	45
	184-L	1.17	0.41	2.34	0.54	0.31	214	51	9	31
Orchard-grass	0	1.17	0.22	2.41	0.30	0.22	410	137	11	94
	7	1.46	0.39	2.59	0.48	0.22	127	87	10	38
	11-L	1.66	0.48	2.69	0.55	0.24	123	79	8	34
	90-L	1.40	0.53	2.76	0.55	0.25	419	62	11	27
	184	1.70	0.63	2.31	0.47	0.23	896	81	12	30
	184-L	1.33	0.51	2.53	0.47	0.23	488	55	11	27

TABLE A-5. MEAN FOLIAR CONCENTRATIONS OF TRACE METALS IN SAMPLES COLLECTED IN 1979 FROM THE VENANGO DEMONSTRATION PROJECT.

Species	Sludge Application	Cu	Zn	Cr	Pb	Co	Cd	Ni
	mt/ha	µg/g						
Birdsfoot Trefoil	0	8.4	38.0	8.5	2.6	0.6	0.10	21.4
	7	9.9	33.8	2.0	3.5	0.1	0.10	7.4
	11-L	8.3	33.2	1.0	3.3	0.8	0.03	4.5
	90-L	8.9	46.2	8.3	1.8	0.4	0.11	15.2
	184	9.8	74.8	0.3	4.4	0.8	0.06	11.3
	184-L	9.2	41.5	1.7	1.8	0.3	0.04	6.3
Crownvetch	7	8.4	49.2	10.3	5.3	1.1	0.11	12.1
	11-L	7.4	35.3	5.4	5.1	0.9	0.05	7.8
	90-L	9.1	58.2	24.4	1.9	2.1	0.05	37.3
	184	10.9	132.6	0.3	3.6	1.2	0.16	5.5
	184-L	8.8	70.9	26.2	2.6	1.3	0.09	33.9
Tall Fescue	0	3.3	9.4	22.4	1.8	0.6	0.06	31.0
	7	5.8	20.9	0.1	3.7	1.0	0.08	0.5
	11-L	5.3	21.8	<0.1	3.0	0.3	0.06	0.8
	90-L	5.3	24.8	8.6	2.8	1.3	0.08	13.0
	184	5.3	48.6	0.3	1.2	0.1	0.06	2.2
	184-L	9.2	72.5	0.5	1.8	0.6	0.08	2.5
Orchard-grass	0	12.4	24.8	7.1	2.4	0.5	0.08	11.8
	7	8.3	28.3	15.1	4.9	0.4	0.10	20.4
	11-L	9.3	27.8	15.4	3.3	0.5	0.05	20.9
	90-L	9.9	44.3	14.6	2.1	0.8	0.15	19.1
	184	9.3	96.1	0.3	1.6	0.4	0.10	5.8
	184-L	8.4	56.9	4.6	3.7	0.3	0.19	8.0
Suggested Tolerance Level*†								

*Melsted (1973)

†Council for Agricultural Science and Technology (1976)

TABLE A-6. MEAN FOLIAR CONCENTRATIONS OF SELECTED CONSTITUENTS ON SAMPLES COLLECTED IN 1980 FROM THE VENANGO DEMONSTRATION PROJECT.

Species	Sludge Rate	N	P	K	Ca	Mg	Mn	Fe	B	Al
	mt/ha	- - - - - -		%		- - - - - -	- - -	µg/g		- - -
Birdsfoot Trefoil	0	2.11	0.17	1.92	1.02	0.23	94	105	26	49
	7	3.08	0.23	2.02	1.02	0.17	44	74	16	31
	11-L	3.14	0.30	2.34	1.38	0.19	51	23	33	34
	90-L	3.48	0.37	2.42	1.93	0.30	137	182	42	82
	184-L	2.93	0.25	1.62	1.27	0.18	79	97	34	42
Crown-vetch	7	3.00	0.21	1.98	1.74	0.19	61	82	15	34
	11-L	2.99	0.22	2.02	1.76	0.23	56	77	18	35
	90-L	3.17	0.23	1.85	2.05	0.29	189	86	22	46
	184-L	3.00	0.27	1.89	1.72	0.29	154	104	23	51
Orchard-grass	0	1.11	0.24	1.86	0.32	0.20	410	864	12	522
	7	1.74	0.25	2.91	0.33	0.20	216	74	6	38
	11-L	1.79	0.26	2.75	0.45	0.25	172	86	9	48
	90-L	1.71	0.34	2.62	0.43	0.21	242	109	7	63
	184-L	1.70	0.42	2.65	0.45	0.23	289	135	10	91
Tall Fescue	0	0.99	0.16	1.18	0.29	0.18	145	355	6	210
	7	1.51	0.26	2.04	0.41	0.21	98	81	5	46
	11-L	1.43	0.29	1.97	0.45	0.23	61	105	7	65
	90-L	1.41	0.38	2.00	0.42	0.30	233	141	10	96
	184-L	1.08	0.34	1.32	0.49	0.22	208	162	8	97

TABLE A-7. MEAN FOLIAR CONCENTRATIONS OF TRACE METALS IN SAMPLES COLLECTED IN 1980 FROM THE VENANGO DEMONSTRATION PROJECT.

Species	Sludge Rate	Cu	Zn	Cr	Pb	Co	Cd	Ni
	mt/ha	- - - - - - - - - - -	- - - - -	- - - - -	µg/g	- - - - -	- - - - -	- - - - - - - - - - -
Birdsfoot Trefoil	0	6.9	32.7	0.6	3.8	2.3	0.13	8.7
	7	7.6	30.5	0.7	3.9	1.4	0.03	4.0
	11-L	7.3	42.9	1.4	4.0	1.6	0.05	6.3
	90-L	14.3	55.4	0.8	6.4	1.7	0.05	11.3
	184-L	8.2	42.3	1.9	4.5	1.4	0.08	6.5
Crownvetch	7	8.3	55.3	0.9	3.7	0.5	0.08	4.5
	11-L	7.4	40.3	0.3	5.8	0.9	0.05	3.9
	90-L	8.3	101.1	1.5	5.0	2.1	0.23	8.3
	184-L	8.9	116.8	7.3	6.2	1.1	0.13	7.4
Orchardgrass	0	10.3	26.2	2.1	4.4	1.5	0.57	5.9
	7	9.5	35.1	5.0	2.5	2.7	0.53	6.3
	11-L	10.8	26.5	0.8	1.6	2.6	0.55	4.6
	90-L	9.3	33.6	1.8	3.7	2.0	0.71	4.1
	184-L	10.4	58.0	5.5	4.3	2.1	0.99	5.8
Tall Fescue	0	3.5	17.2	0.7	7.6	1.6	0.32	4.6
	7	8.9	36.9	1.3	3.3	2.3	0.35	7.3
	11-L	3.9	17.0	1.3	2.3	2.0	0.21	6.7
	90-L	8.3	30.1	1.3	2.7	2.0	0.78	6.2
	184-L	3.5	41.9	1.1	3.8	1.8	0.73	7.3

TABLE A-8. MEAN FOLIAR CONCENTRATIONS OF SELECTED CONSTITUENTS IN SAMPLES COLLECTED IN 1981 FROM THE VENANGO DEMONSTRATION PROJECT.

Species	Sludge Application	N	P	K	Ca	Mg	Mn	Fe	B	Al
	mt/ha			%				μg/g		
Birdsfoot Trefoil	0	3.32	0.17	1.89	1.52	0.29	113	95	34	35
	7	3.70	0.26	2.02	1.32	0.19	52	89	20	25
	11-L	3.48	0.23	1.87	1.12	0.18	38	69	25	22
	90-L	3.59	0.25	1.77	1.07	0.24	99	74	29	25
	184-L	4.03	0.26	1.69	1.14	0.23	119	89	27	27
Crownvetch	0	1.74	0.14	1.56	2.26	0.34	98	65	21	28
	7	5.08	0.36	2.15	1.62	0.21	57	94	16	16
	11-L	4.68	0.32	1.89	1.58	0.22	42	84	19	17
	90-L	4.98	0.34	1.93	1.57	0.30	130	100	19	24
	184-L	3.78	0.31	1.89	1.25	0.23	110	84	20	20
Tall Fescue	0	0.95	0.15	1.28	0.46	0.24	165	138	7	135
	7	1.95	0.36	2.28	0.44	0.32	69	64	6	24
	11-L	1.83	0.28	1.98	0.59	0.25	64	69	7	38
	90-L	2.10	0.33	2.15	0.44	0.24	143	49	7	25
	184-L	2.34	0.33	2.37	0.63	0.33	165	70	7	30
Orchard-grass	0	1.22	0.18	1.62	0.68	0.22	282	455	10	350
	7	2.51	0.24	3.20	0.57	0.35	120	53	6	25
	11-L	2.51	0.21	2.43	0.47	0.26	66	62	6	21
	90-L	2.97	0.29	2.54	0.68	0.23	189	66	11	26
	184-L	2.57	0.37	2.38	0.53	0.26	157	67	7	25

TABLE A-9. MEAN FOLIAR CONCENTRATION OF TRACE METALS IN SAMPLES COLLECTED IN 1981 FROM THE VENANGO DEMONSTRATION PROJECT.

Species	Sludge Application	Cu	Zn	Cr	Pb	Co	Cd	Ni
	mt/ha	- - - - - - - - - - - µg/g - - - - - - - - - - -						
Birdsfoot Trefoil	0	9.3	27.0	<0.1	5.5	1.3	0.50	7.7
	7	10.1	28.1	<0.1	2.0	1.2	0.18	0.3
	11-L	8.8	22.8	<0.1	2.7	0.9	0.18	2.2
	90-L	9.8	29.2	<0.1	1.0	0.5	0.20	2.9
	184-L	11.6	40.9	<0.1	1.5	0.9	0.37	3.3
Crownvetch	0	6.8	19.8	<0.1	2.9	1.3	0.18	0.3
	7	10.5	50.3	<0.1	1.8	1.3	0.36	1.5
	11-L	9.9	40.0	<0.1	1.8	1.0	0.29	1.5
	90-L	10.8	70.7	<0.1	1.9	1.4	0.67	5.7
	184-L	10.3	70.6	<0.1	2.3	1.3	0.54	3.5
Tall Fescue	0	6.6	10.0	<0.1	3.2	<0.1	0.27	<0.1
	7	10.4	19.8	<0.1	0.4	0.8	0.35	<0.1
	11-L	7.2	19.1	<0.1	0.9	0.4	0.54	0.3
	90-L	10.2	25.6	<0.1	0.8	1.1	0.50	1.6
	184-L	12.7	34.8	<0.1	1.9	1.0	0.50	0.7
Orchardgrass	0	6.8	21.6	<0.1	1.4	1.3	0.58	1.4
	7	11.9	35.2	<0.1	<0.1	0.7	0.58	<0.1
	11-L	11.8	22.6	<0.1	0.6	0.8	0.18	<0.1
	90-L	11.9	52.0	<0.1	<0.1	0.7	0.06	3.1
	184-L	15.0	42.4	<0.1	2.4	0.8	0.06	0.3

TABLE A-10. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1980.

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - - mg/l - - - - - - - - -				
0	Jan	0.008	<0.5	0.57	0.35	4.1
	March	0.006	<0.5	0.48	0.09	4.3
	April	0.008	<0.5	0.50	0.31	4.1
	May	0.009	<0.5	0.66	0.23	4.4
	June	0.009	<0.5	0.80	0.19	3.9
	July	0.003	1.7	0.91	0.18	4.0
	Aug	0.018	<0.5	0.72	0.08	4.1
	Sept	0.036	2.2	0.29	2.67	2.7
	Oct	0.017	<0.5	0.91	<0.05	2.8
	Nov	0.019	<0.5	0.16	0.06	3.8
7	Jan	0.008	0.5	0.08	0.33	7.2
	March	0.012	2.7	0.22	0.26	7.4
	April	0.110	2.1	0.06	0.31	7.0
	May	0.008	1.5	0.06	0.21	8.0
	June	0.007	4.2	0.06	0.30	7.8
	July	0.001	64.0*	0.31	0.45	7.6
	Aug	0.022	4.4	0.08	0.59	7.5
	Oct	0.001	10.4	0.74	--	7.9
	Nov	0.011	4.6	0.05	0.73	7.7
11-L	Jan	0.009	<0.5	0.20	0.24	4.0
	March	0.012	<0.5	0.26	0.28	3.8
	April	0.017	<0.5	0.21	0.37	4.0
	May	0.018	<0.5	0.30	0.15	3.9
	June	0.024	0.8	0.32	0.23	3.9
	July	0.007	<0.5	0.61	0.35	4.0
	Aug	0.017	<0.5	0.29	0.48	3.9
	Sept	0.026	2.0	1.24	0.28	3.8
	Oct	0.089	1.7	0.67	0.14	4.3
	Nov	0.020	0.7	0.18	0.04	3.9
90-L	Jan	0.030	0.5	4.48	1.70	3.7
	March	0.015	0.5	4.52	4.20	3.8
	April	0.016	0.5	1.46	0.68	3.7
	May	0.015	0.5	1.89	0.12	3.6
	June	0.022	1.1	3.30	0.08	3.5
	July	0.013	1.6	2.82	0.11	3.4
	Aug	0.005	1.0	3.12	0.23	3.3
	Sept	0.027	7.6	1.36	0.33	3.2
	Oct	0.018	7.2	2.88	0.00	3.4
	Nov	0.017	9.0	0.44	0.00	3.5

(Continued)

TABLE A-10. (Continued)

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - -	mg/l	- - - - - - - - -		
184-L	Jan	0.010	<0.5	0.07	0.23	3.9
	March	0.015	0.7	0.10	0.08	4.0
	April	0.015	<0.5	0.12	0.24	4.0
	May	0.017	<0.5	0.06	0.20	3.9
	June	0.017	<0.5	0.12	0.17	3.8
	July	0.008	<0.5	0.10	0.08	3.5
	Aug	0.023	<0.5	0.12	0.13	4.0
	Sept	0.033	1.0	0.15	0.08	3.5
	Oct	0.071	<0.5	0.14	<0.05	3.7
	Nov	0.023	<0.5	0.06	<0.05	3.9

*Instrument problems in the lab. This value is questionable.

TABLE A-11. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1981.

Sludge Application	Month	Ortho P	NO$_3$-N	NH$_4$-N	Org-N	pH
mt/ha		- - - - - - - - - mg/l - - - - - - - - -				
0	Jan	--	--	--	--	--
	Feb	.001	0.5	0.17	0.08	7.7
	March	.009	0.5	0.49	0.10	4.3
	April	.013	0.5	0.56	0.12	4.2
	May	.006	1.5	0.54	0.19	4.1
	June	.053	18.3*	0.67	0.48	4.1
	July	.041	0.8	0.88	0.17	4.0
	Aug	.027	2.0	0.85	0.37	4.2
	Sept	.002	0.5	0.35	0.53	4.1
	Oct	.013	1.6	0.39	0.88	3.9
	Nov	--	--	--	--	--
	Dec	.036	0.7	0.29	0.03	4.0
7	Jan	--	--	--	--	--
	Feb	.022	6.6	0.05	0.18	7.8
	March	.024	8.7	0.08	0.20	7.5
	April	.024	6.9	0.06	0.15	7.6
	May	.038	42.3*	0.06	0.19	7.0
	June	.069	41.3*	0.09	0.65	7.0
	July	.022	4.4	0.30	0.49	8.0
	Aug	.060	8.0	0.20	--	7.9
	Sept	.005	6.6	0.26	0.98	7.6
	Oct	.023	5.2	0.05	0.71	6.6
	Nov	--	--	--	--	--
	Dec	.023	15.8	0.05	0.29	6.6
11-L	Jan	--	--	--	--	--
	Feb	.009	0.8	0.21	0.29	4.1
	March	.024	0.5	0.12	0.07	4.1
	April	.022	1.2	0.27	0.12	4.0
	May	.014	3.0	0.13	0.19	4.1
	June	.046	1.0	0.16	0.54	3.8
	July	.032	1.3	0.68	0.22	3.8
	Aug	.038	1.0	0.39	0.78	3.9
	Sept	.016	1.4	0.28	0.81	3.6
	Oct	.016	2.0	0.40	1.28	3.4
	Nov	--	--	--	--	--
	Dec	.076	3.3	0.16	0.15	3.8

(Continued)

TABLE A-11. (Continued)

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - -	- - - -	mg/l - - - -	- - - - - - - - -	
90-L	Jan	--	--	--	--	--
	Feb	.001	0.5	0.25	0.23	3.9
	March	.020	1.6	0.14	0.12	3.8
	April	.020	2.3	3.62	0.05	3.7
	May	.001	2.6	1.28	2.33	3.6
	June	.051	4.0	3.95	0.36	3.3
	July	.009	11.0*	1.13	0.00	3.5
	Aug	.047	7.5	0.88	0.30	3.6
	Sept	.008	5.7	0.40	0.56	3.5
	Oct	.029	3.0	0.15	0.33	3.4
	Nov	--	--	--	--	--
	Dec	.047	4.2	0.09	0.20	3.7
184-L	Jan	--	--	--	--	--
	Feb	.007	0.5	0.08	0.23	4.1
	March	.026	0.5	0.08	2.64	4.0
	April	.026	0.8	0.15	0.22	3.9
	May	.011	1.2	0.14	0.34	3.9
	June	.054	1.0	0.99	0.46	3.4
	July	.023	0.5	0.08	0.22	4.0
	Aug	.032	0.8	0.10	0.30	3.7
	Sept	.011	0.5	0.05	0.28	3.7
	Oct	.064	0.8	0.05	0.55	3.6
	Nov	--	--	--	--	--
	Dec	.037	0.9	0.05	0.09	3.9

* Instrument problems in the lab. These values are questionable.

TABLE A-12. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION PROJECT FOR 1982.

Sludge Application	Month	Ortho P	NO_3-N	NH_4-N	Org-N	pH
mt/ha		- - - - - - - - -	- - - -	mg/l	- - - -	- - - - - - - - -
0	Jan	--	--	--	--	--
	Feb	--	--	--	--	--
	March	.018	0.5	0.23	0.11	4.2
	April	.023	0.5	0.12	0.45	4.3
7	Jan	--	--	--	--	--
	Feb	--	--	--	--	--
	March	.022	9.4	0.05	0.15	6.6
	April	.007	9.6	0.05	0.15	7.5
11-L	Jan	--	--	--	--	--
	Feb	--	--	--	--	--
	March	.008	2.2	0.20	0.12	4.0
	April	.030	4.5	0.10	0.20	4.2
90-L	Jan	--	--	--	--	--
	Feb	--	--	--	--	--
	March	.009	0.8	0.33	0.14	4.0
	April	.016	1.4	0.23	0.40	3.8
184-L	Jan	--	--	--	--	--
	Feb	--	--	--	--	--
	March	.007	1.2	0.05	0.22	3.6
	April	.015	0.5	0.05	0.36	4.1

TABLE A-13. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CATIONS AT THE VENANGO DEMONSTRATION PROJECT FOR 1980.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - - - - - - - -	- - - -	- - -	mg/l - - -	- - - -	- - - -	- - - -
0	Jan	10.57	1.53	22.40	0.82	193	199	1.37
	March	1.15	0.72	12.60	2.14	106	33	1.37
	April	11.44	1.77	19.15	0.78	155	39	1.14
	May	1.65	0.75	6.65	10.01	167	37	1.71
	June	10.85	1.03	24.43	4.73	29	36	3.73
	July	14.67	1.59	33.69	4.05	84	40	4.10
	Aug	59.68	2.24	33.37	4.25	62	31	3.92
	Sept	90.27	4.62	72.45	0.68	<1	42	4.55
	Oct	13.67	3.69	67.80	0.53	1	29	3.11
	Nov	12.78	3.40	55.83	1.35	303	66	3.84
7	Jan	0.03	0.01	0.20	1.05	168	15.6	1.58
	March	<0.01	0.01	0.17	0.37	107	8.8	1.14
	April	0.05	0.03	0.21	0.67	164	8.4	1.22
	May	0.01	0.01	0.04	4.21	137	9.9	1.58
	June	0.01	0.02	0.01	1.05	77	15.3	2.68
	July	0.01	0.02	0.04	1.67	67	13.0	4.25
	Aug	0.03	0.05	0.05	1.35	65	13.0	2.31
	Oct	0.05	0.08	0.08	5.25	<1	6.0	3.75
	Nov	0.01	0.02	0.10	2.64	321	20.1	3.65
11-L	Jan	0.71	2.23	13.10	4.08	311	28.9	2.23
	March	0.33	0.99	6.24	2.30	175	11.4	2.16
	April	0.53	1.43	5.35	1.78	251	12.3	1.80
	May	0.26	1.04	3.40	6.62	245	13.6	2.68
	June	0.16	1.75	10.91	1.92	344	19.5	5.19
	July	0.44	5.25	1.32	4.25	191	25.0	3.33
	Aug	0.27	2.04	8.53	2.82	277	22.3	3.01
	Sept	0.44	1.90	9.60	3.26	<1	<0.1	4.83
	Oct	0.20	2.90	8.40	8.71	178	15.0	4.63
	Nov	0.73	3.76	10.94	3.98	457	21.8	6.43
90-L	Jan	0.23	5.26	15.85	2.82	306	41.3	0.95
	March	0.07	4.57	7.65	3.07	825	32.3	0.83
	April	21.12	6.66	31.21	1.87	271	35.5	0.87
	May	19.05	6.40	20.50	1.98	219	24.6	0.96
	June	62.54	6.76	35.69	3.33	163	27.7	2.52
	July	0.31	15.61	19.97	4.68	332	41.0	2.65
	Aug	131.15	18.06	38.90	5.51	265	45.3	3.18
	Sept	87.66	9.65	10.03	5.87	347	43.0	11.71
	Oct	41.82	12.37	77.45	5.04	149	60.0	3.24
	Nov	0.54	2.71	14.20	9.36	209	29.7	4.61

(Continued)

TABLE A-13. (Continued)

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - - - - - - - - mg/l - - - - - - - - - - -						
184-L	Jan	0.82	1.58	7.90	3.14	104	11.0	0.93
	March	0.82	1.10	4.51	2.20	42	5.0	0.82
	April	0.29	1.15	3.47	1.93	72	4.1	0.95
	May	0.46	1.58	3.83	2.54	43	1306	0.70
	June	0.65	0.64	5.16	4.20	27	7.0	3.07
	July	1.40	0.80	4.70	4.15	27	7.7	2.51
	Aug	0.05	0.93	6.16	4.70	29	8.0	2.87
	Sept	0.13	0.94	6.41	4.42	15	6.3	4.17
	Oct	0.77	1.06	6.57	4.18	<1	0.7	2.58
	Nov	1.00	1.72	8.52	4.14	85	13.7	2.92

TABLE A-14. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CATIONS AT THE VENANGO DEMONSTRATION PROJECT FOR 1981.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - - -	- - - - - -	- - - - - -	mg/l	- - - - - -	- - - - - -	- - - - - -
0	Feb	<1	0.04	0.2	2.22	123	77.4	4.52
	March	19.5	2.97	45.6	0.95	129	59.1	0.64
	April	16.0	1.25	15.8	1.00	94	36.1	0.82
	May	5.6	0.76	8.3	1.09	83	26.9	0.68
	June	9.9	1.08	10.5	1.37	89	32.6	0.72
	July	11.4	1.47	15.2	1.41	103	41.8	1.04
	Aug	5.1	1.48	12.6	1.51	103	40.3	1.43
	Sept	78.1	2.05	19.8	3.33	120	50.7	1.61
	Oct	7.4	2.17	22.1	1.19	116	53.9	1.99
	Nov	4.7	1.78	17.9	1.20	114	48.3	1.97
	Dec	5.1	1.70	19.5	1.04	113	32.8	1.52
7	Feb	0.01	0.01	0.17	0.99	56	11.4	0.82
	March	0.01	0.02	0.07	1.45	129	13.0	0.79
	April	0.01	0.01	0.09	2.02	114	11.6	1.06
	May	0.01	0.01	0.01	1.50	120	12.1	1.08
	June	0.01	0.01	0.03	0.91	127	13.1	0.57
	July	0.01	0.01	0.01	1.23	128	14.4	0.43
	Aug	0.01	0.02	0.01	0.73	95	14.3	0.67
	Sept	0.01	0.01	0.01	1.40	197	20.7	1.21
	Oct	0.02	0.01	0.01	1.85	146	16.7	1.81
	Nov	0.01	0.01	0.01	2.34	163	18.4	1.80
	Dec	0.01	0.01	0.04	1.61	149	30.4	1.56
11-L	Feb	0.31	2.34	5.67	1.89	257	22.7	1.77
	March	0.37	1.72	4.61	1.51	220	19.8	1.07
	April	0.07	1.21	2.82	1.72	183	13.8	1.07
	May	0.01	0.90	2.04	1.65	163	11.9	1.07
	June	0.01	1.20	2.76	1.61	175	14.9	0.79
	July	0.11	1.84	3.78	1.43	174	14.7	1.01
	Aug	0.13	2.00	3.89	2.14	183	18.0	1.12
	Sept	0.66	3.88	40.45	4.40	279	38.8	2.94
	Oct	0.46	5.93	10.60	2.88	313	46.5	4.17
	Nov	0.29	4.08	8.02	2.51	307	39.4	3.30
	Dec	0.24	3.56	7.40	2.00	260	31.4	2.59

(Continued)

TABLE A-14. (Continued)

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		mg/l						
90-L	Feb	0.14	5.11	5.69	2.75	131	23.0	1.57
	March	0.19	4.36	5.50	3.18	108	19.9	0.41
	April	0.10	2.85	4.50	3.87	71	13.8	0.46
	May	0.07	4.13	4.76	4.02	118	17.8	0.49
	June	0.29	8.32	6.72	4.29	148	31.9	0.55
	July	0.30	1.16	5.24	7.24	48	5.6	0.80
	Aug	0.44	12.33	10.80	3.64	161	44.0	1.03
	Sept	0.37	14.36	12.69	2.75	215	65.7	1.27
	Oct	0.21	11.55	11.50	2.32	203	60.2	1.70
	Nov	0.15	12.01	11.90	2.09	181	54.3	1.52
	Dec	0.09	5.82	8.33	1.81	150	35.7	1.24
184-L	Feb	0.07	1.28	4.50	2.55	56	8.2	0.47
	March	0.08	1.05	3.56	2.35	52	7.2	0.37
	April	0.06	0.99	3.32	3.07	47	6.7	0.48
	May	0.03	0.83	2.95	2.94	46	6.1	0.39
	June	0.28	0.85	3.06	3.41	43	6.1	0.44
	July	0.05	0.88	3.83	2.97	43	7.4	0.73
	Aug	0.27	0.96	3.28	3.56	48	6.9	0.57
	Sept	0.21	1.30	4.80	3.85	55	8.9	0.58
	Oct	0.25	1.55	5.65	3.95	63	10.7	1.29
	Nov	0.25	1.61	4.91	4.19	67	11.3	1.22
	Dec	0.11	1.66	5.73	3.73	63	11.5	1.00

TABLE A-15. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CATIONS AT THE VENANGO DEMONSTRATION PROJECT FOR 1982.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - - - - - - - - mg/l - - - - - - - - - - - -						
0	March	0.87	0.61	6.27	0.97	78	26.6	0.99
	April	3.61	1.14	11.80	1.20	65	32.8	1.48
7	March	0.01	0.02	0.01	2.02	126	12.6	1.33
	April	0.02	0.01	0.01	2.26	119	12.6	1.70
11-L	March	0.03	1.05	3.33	1.80	147	11.6	1.30
	April	0.10	1.18	3.23	2.38	135	12.8	1.69
90-L	March	0.54	1.86	2.55	2.26	54	10.7	0.70
	April	1.08	2.32	3.55	2.62	71	13.0	1.37
184-L	March	0.19	1.17	3.73	3.20	45	7.3	0.59
	April	0.38	1.25	4.27	3.66	49	7.4	0.89

TABLE A-16. SOIL PERCOLATE WATER ANALYSES FOR TRACE METALS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1980.

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha		- - - - - - - - - - - -	- - - - - -	- - - -	mg/l	- - - -	- - - - - -	- - - -
0	Jan	0.04	0.37	0.04	0.06	0.09	<0.001	0.18
	March	0.03	0.32	0.03	0.09	0.04	<0.001	0.08
	April	0.07	0.51	0.02	0.06	0.07	0.001	0.08
	May	0.02	0.26	0.01	0.01	0.03	<0.001	0.14
	June	0.05	0.47	0.05	0.02	0.06	<0.001	0.05
	July	0.07	0.68	0.05	0.02	0.06	0.001	0.14
	Aug	0.07	1.23	0.07	0.07	0.05	<0.001	0.22
	Sept	0.14	1.71	0.11	0.06	0.07	<0.001	0.24
	Oct	0.10	2.71	0.08	0.03	0.18	0.001	0.42
	Nov	0.09	0.72	0.04	0.19	0.17	0.001	0.42
						0.19	0.001	0.30
7	Jan	0.01	0.10	0.01	0.01	0.01	<0.001	0.03
	March	0.01	0.08	0.02	0.03	0.01	<0.001	0.07
	April	0.02	0.07	0.01	0.04	0.01	<0.001	0.04
	May	0.02	0.16	0.01	0.01	0.01	<0.001	0.01
	June	0.01	0.07	0.01	0.01	0.01	<0.001	0.04
	July	0.01	0.14	0.01	0.01	0.01	<0.001	0.03
	Aug	0.01	0.16	0.01	0.04	0.01	<0.001	0.04
	Oct	0.02	1.36	0.01	0.02	0.01	<0.001	0.07
	Nov	0.04	0.47	0.01	0.11	0.03	<0.001	0.01
11-L	Jan	0.06	0.93	0.02	0.09	0.15	0.001	0.30
	March	0.04	0.55	0.01	0.10	0.06	0.001	0.16
	April	0.05	0.50	0.01	0.06	0.07	0.002	0.14
	May	0.01	0.48	0.01	0.02	0.05	<0.001	0.11
	June	0.06	0.65	0.01	0.05	0.13	0.001	0.29
	July	0.05	1.43	0.03	0.05	0.22	<0.001	0.46
	Aug	0.03	0.89	0.01	0.05	0.10	0.001	0.29
	Sept	0.07	1.01	0.01	0.02	0.11	0.002	0.25
	Oct	0.10	1.22	0.02	0.04	0.27	0.001	0.30
	Nov	0.07	0.72	0.01	0.03	0.23	0.003	0.33
90-L	Jan	0.01	0.54	0.03	0.02	0.15	0.001	0.29
	March	0.02	0.40	0.02	0.08	0.06	<0.001	0.15
	April	0.11	0.97	0.02	0.05	0.17	0.004	0.56
	May	0.08	0.94	0.01	0.04	0.18	0.001	0.23
	June	0.05	1.07	0.02	0.05	0.16	0.001	0.39
	July	0.03	0.77	0.02	0.02	0.18	0.001	0.41
	Aug	0.04	1.55	0.02	0.08	0.24	0.002	0.66
	Sept	0.07	1.89	0.04	0.11	0.23	0.002	0.61
	Oct	0.20	2.26	0.06	0.11	0.88	0.002	0.85
	Nov	0.04	0.67	0.01	0.10	0.15	0.002	0.24

(Continued)

TABLE A-16. (Continued)

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha					mg/l			
184-L	Jan	0.01	0.63	0.01	0.06	0.09	0.001	0.15
	March	0.01	0.34	0.01	0.04	0.04	0.001	0.09
	April	0.02	0.52	0.01	0.02	0.05	0.001	0.08
	May	0.01	0.48	0.01	0.01	0.05	<0.001	0.01
	June	0.02	0.44	0.01	0.01	0.05	<0.001	0.10
	July	0.02	0.51	0.01	0.02	0.05	0.001	0.12
	Aug	0.02	0.39	0.01	0.05	0.03	0.001	0.13
	Sept	0.02	0.58	0.03	0.03	0.04	0.001	0.10
	Oct	0.02	0.63	0.01	0.03	0.06	0.001	0.15
	Nov	0.03	0.59	0.01	0.07	0.12	0.001	0.15

TABLE A-17. SOIL PERCOLATE WATER ANALYSES FOR TRACE METALS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1981.

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha		- - - - - -	- - - - - -	- - - - - -	-mg/l-	- - - - - -	- - - - - -	- - - - - -
0	Feb	0.01	0.12	0.01	0.05	0.02	0.008	0.01
	March	0.09	0.65	0.05	0.02	0.10	0.001	0.19
	April	0.06	0.26	0.04	0.02	0.08	0.001	0.09
	May	0.05	0.06	0.03	0.01	0.04	<0.001	0.08
	June	0.06	0.26	0.03	0.01	0.07	<0.001	0.08
	July	0.06	0.50	0.05	0.01	0.08	<0.001	0.13
	Aug	0.08	0.43	0.05	0.02	0.08	0.001	0.10
	Sept	0.04	0.34	0.05	0.01	0.09	0.001	0.12
	Oct	0.05	0.46	0.01	0.06	0.08	0.001	0.19
	Nov	0.04	0.41	0.01	0.06	0.05	<0.001	0.14
	Dec	0.04	0.48	0.05	0.08	0.06	0.001	0.14
7	Feb	0.01	0.02	0.01	0.03	0.01	<0.001	0.01
	March	0.02	0.07	0.01	0.01	0.01	<0.001	0.01
	April	0.02	0.02	0.02	0.01	0.04	<0.001	0.01
	May	0.01	0.09	0.03	0.01	0.02	<0.001	0.02
	June	0.02	0.01	0.03	0.01	0.01	<0.001	0.01
	July	0.02	0.14	0.04	0.01	0.01	<0.001	0.01
	Aug	0.05	0.34	0.03	0.01	0.02	<0.001	0.01
	Sept	0.02	0.12	0.04	0.01	0.01	0.002	0.01
	Oct	0.01	0.09	0.01	0.05	0.01	<0.001	0.02
	Nov	0.01	0.10	0.01	0.01	0.01	0.001	0.01
	Dec	0.01	0.11	0.02	0.04	0.01	0.002	0.01
11-L	Feb	0.03	0.77	0.01	0.03	0.15	0.004	0.20
	March	0.04	0.40	0.02	0.02	0.11	0.002	0.10
	April	0.03	0.36	0.02	0.01	0.08	0.001	0.12
	May	0.03	0.12	0.02	0.02	0.06	0.001	0.11
	June	0.02	0.28	0.03	0.03	0.07	0.001	0.12
	July	0.04	0.79	0.03	0.01	0.08	0.001	0.13
	Aug	0.04	0.63	0.03	0.01	0.13	0.001	0.13
	Sept	0.06	0.74	0.04	0.01	0.18	0.002	0.26
	Oct	0.06	1.03	0.01	0.16	0.25	0.002	0.56
	Nov	0.04	0.85	0.01	0.01	0.19	0.002	0.42
	Dec	0.04	0.89	0.01	0.04	0.16	0.002	0.35

(Continued)

TABLE A-17. (Continued)

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha		- - - - - - - - - - - -			mg/l	- - - - - - - - - - - -		
90-L	Feb	0.01	0.48	0.01	0.02	0.09	0.004	0.12
	March	0.03	0.30	0.01	0.03	0.09	0.011	0.09
	April	0.03	0.22	0.02	0.03	0.08	<0.001	0.10
	May	0.03	0.28	0.03	0.02	0.10	<0.001	0.10
	June	0.05	0.42	0.03	0.02	0.15	0.001	0.20
	July	0.03	0.43	0.03	0.01	0.06	0.001	0.08
	Aug	0.05	0.61	0.03	0.01	0.23	0.002	0.22
	Sept	0.05	0.50	0.03	0.02	0.21	0.005	0.38
	Oct	0.03	0.68	0.01	0.05	0.14	<0.001	0.42
	Nov	0.03	0.50	0.01	0.05	0.21	<0.001	0.37
	Dec	0.01	0.35	0.01	0.01	0.10	0.001	0.23
184-L	Feb	0.01	0.56	0.01	0.02	0.08	0.004	0.06
	March	0.03	0.34	0.01	0.01	0.09	0.003	0.04
	April	0.03	0.27	0.01	0.01	0.09	<0.001	0.06
	May	0.04	0.27	0.02	0.01	0.08	<0.001	0.03
	June	0.03	0.26	0.03	0.02	0.05	0.001	0.09
	July	0.03	0.32	0.03	0.01	0.07	0.001	0.05
	Aug	0.03	0.32	0.03	0.01	0.07	0.001	0.04
	Sept	0.03	0.22	0.03	0.01	0.06	0.001	0.03
	Oct	0.02	0.46	0.01	0.05	0.06	<0.001	0.15
	Nov	0.02	0.44	0.01	0.04	0.06	0.001	0.13
	Dec	0.02	0.55	0.01	0.01	0.08	0.001	0.12

TABLE A-18. SOIL PERCOLATE WATER ANALYSES FOR TRACE METALS AT THE VENANGO COUNTY DEMONSTRATION PROJECT DURING 1982.

Sludge Application	Month	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha		- - - - - - - - - - - - - mg/l - - - - - - - - - - - - -						
0	March	0.03	0.21	0.02	0.05	0.05	<0.001	0.11
	April	0.02	0.21	0.01	0.03	0.03	<0.001	0.06
7	March	0.01	0.08	0.01	0.01	0.01	<0.001	0.05
	April	0.01	0.08	0.01	0.02	0.01	<0.001	0.02
11-L	March	0.02	0.22	0.01	0.04	0.06	0.001	0.13
	April	0.01	0.25	0.01	0.03	0.07	0.001	0.11
90-L	March	0.01	0.13	0.01	0.02	0.04	<0.001	0.08
	April	0.01	0.15	0.01	0.03	0.06	0.001	0.10
184-L	March	0.01	0.34	0.01	0.02	0.07	0.001	0.11
	April	0.01	0.37	0.01	0.01	0.06	<0.001	0.09

TABLE A-19. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION SITE FOR 1980.

Well No.	Month	Fe	Mn	Al	K	Ca	Mg	Na
		- - - - - -	- - - - - -	- - - - - -	mg/l	- - - - - -	- - - - - -	- - - - - -
1	Jan	481	96.1	1.50	7.91	468	1604	7.90
	Feb	547	53.5	1.60	7.86	370	1313	8.70
	March	527	81.8	1.23	3.80	444	1475	9.70
	April	1043	120.0	0.62	9.11	462	251	12.10
	May	956	115.0	1.10	9.10	452	271	12.30
	June	<1	<1	0.01	0.02	<1	<1	2.00
	July	1887	199.0	2.38	10.10	600	24	18.00
	Aug	1860	199.0	4.63	8.76	710	320	17.19
	Sept	1839	24.6	1.70	8.66	640	260	2.89
	Oct	1835	199.0	0.73	8.17	127	230	14.91
	Nov	837	129.0	1.56	7.91	597	285	17.3
2	Jan	245	89.2	2.20	5.99	320	1105	3.40
	Feb	300	8.2	2.30	5.74	444	998	4.20
	March	302	54.5	1.64	5.49	1940	847	3.90
	April	308	77.9	2.09	6.41	495	150	5.51
	May	309	79.4	1.20	8.81	455	148	6.16
	June	207	196.0	1.08	7.35	660	120	9.91
	July	207	197.0	1.51	6.61	590	11	8.99
	Aug	210	198.0	2.24	7.68	720	190	9.74
	Sept	206	195.0	0.90	7.24	720	130	15.69
	Oct	162	16.6	1.10	6.93	110	150	8.04
	Nov	391	68.4	1.64	6.19	508	130	8.46
3	Jan	318	9.2	0.10	4.59	319	87	9.20
	Feb	92	10.0	0.30	1.64	279	75	9.20
	March	293	12.7	1.70	2.05	325	545	10.80
	April	114	13.7	0.14	1.83	324	73	12.80
	May	146	14.9	1.10	1.93	313	57	13.10
	June	188	6.5	0.07	2.17	158	40	15.90
	July	181	4.4	0.16	2.18	132	50	16.40
	Aug	180	4.7	0.87	2.51	139	60	17.22
	Sept	5	2.5	0.01	2.90	43	60	8.63
	Oct	19	2.1	0.08	2.91	<1	26	18.72
	Nov	14	1.5	0.35	2.11	320	64	18.10

TABLE A-20. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION SITE FOR 1981.

Well No.	Month	Fe	Mn	Al	K	Ca	Mg	Na
		- - - -	- - - -	- - - -	- - - -	mg/l	- - - -	- - - -
1	Feb	570	31.9	1.12	9.09	474	288	14.0
	March	390	33.7	2.24	9.09	259	280	12.5
	April	350	31.7	1.73	9.33	461	284	13.9
	May	660	29.4	0.68	8.50	453	304	12.8
	June	540	27.8	0.63	9.33	433	255	16.1
	July	220	30.5	0.01	8.82	456	280	13.6
	Aug	200	95.6	0.46	8.43	444	282	15.0
	Sept	220	101.0	0.55	8.51	463	280	17.3
	Oct	690	464.0	0.25	8.02	437	289	16.3
	Nov	690	29.6	0.07	9.41	516	33	19.0
	Dec	192	98.0	0.30	8.00	452	298	13.9
2	Feb	262	17.0	0.56	4.32	412	123	4.99
	March	150	19.8	0.96	5.96	470	154	5.11
	April	330	18.5	0.75	6.16	503	157	5.09
	May	120	18.3	0.60	6.24	507	152	6.76
	June	250	16.3	0.52	6.44	481	141	7.66
	July	216	16.4	0.27	6.09	48	11	6.26
	Aug	242	47.1	0.13	5.69	483	129	5.93
	Sept	234	42.7	0.24	6.35	494	127	8.63
	Oct	307	39.0	0.22	6.50	465	133	5.90
	Nov	277	44.6	0.08	6.78	500	14	5.89
	Dec	300	46.5	0.22	6.31	466	136	5.90
3	Feb	14	4.2	0.70	2.72	296	87	14.5
	March	149	15.6	0.24	2.03	501	73	9.17
	April	139	14.0	0.08	2.08	241	73	12.6
	May	116	9.6	0.03	1.77	202	70	11.0

TABLE A-21. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO COUNTY DEMONSTRATION SITE FOR 1982.

Well No.	Month	Fe	Mn	Al	K	Ca	Mg	Na
		mg/l						
1	Feb	749	92.1	0.32	8.77	451	293	15.3
	March	617	97.1	0.50	8.77	459	272	14.2
	April	516	97.8	0.40	8.49	467	289	16.1
2	Feb	301	48.9	0.54	6.19	482	118	6.3
	March	160	51.7	0.50	6.09	492	142	5.7
	April	189	54.4	0.40	6.24	538	147	7.1

TABLE A-22. LAKE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO DEMONSTRATION PROJECT DURING 1980.

Lake No. and Month		Fe	Mn	Cr	Co	Pb	Ni	Al	K	Ca	Mg	Na
							mg/l					
1	April	0.67	6.81	0.01	0.14	0.05	0.10	1.77	2.02	73	13.2	16.9
	May	0.83	6.93	0.01	0.14	0.01	0.07	1.10	2.17	87	21.9	17.2
	June	0.30	5.60	0.01	0.08	0.02	0.21	2.07	2.64	35	22.0	20.3
	July	0.55	6.51	0.01	0.10	0.01	0.19	2.46	2.92	36	23.0	27.6
	Aug	0.98	7.43	0.01	0.14	0.01	0.20	2.86	2.96	52	29.0	27.0
	Sept	0.41	8.36	0.01	0.13	0.07	0.24	2.89	3.38	53	29.0	26.6
	Oct	0.25	7.32	0.01	0.10	0.01	0.20	2.46	2.59	<1	12.0	17.6
	Nov	0.06	7.46	0.02	0.11	0.01	0.16	2.36	2.66	102	29.4	20.2
2	April	1.29	0.99	0.01	0.01	0.01	0.01	0.33	1.35	70	7.7	0.78
	May	0.63	0.66	0.01	0.03	0.06	0.01	0.01	1.43	60	10.5	0.98
	June	0.45	0.14	0.01	0.01	0.01	0.01	0.12	4.17	35	13.0	2.91
	July	0.08	0.10	0.01	0.01	0.01	0.04	0.06	2.20	39	15.0	3.12
	Aug	0.21	0.20	0.01	0.01	0.04	0.03	0.03	1.97	42	15.0	2.74
	Sept	0.38	0.17	0.03	0.01	0.06	0.04	0.01	2.40	47	16.0	2.56
	Oct	0.15	0.09	0.01	0.01	0.04	0.04	0.01	2.40	<1	3.0	1.87
	Nov	0.06	0.01	0.01	0.01	0.06	0.01	0.08	2.61	91	17.9	2.44

TABLE A-23. LAKE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO DEMONSTRATION PROJECT DURING 1981.

Lake No. and Month	Fe	Mn	Cr	Co	Pb	Ni	Al	K	Ca	Mg	Na
						mg/l					
1 April	0.41	4.63	0.01	0.08	0.01	0.10	0.77	2.31	63.0	19.4	16.6
May	0.31	4.26	0.02	0.10	0.02	0.08	0.66	2.08	62.0	19.6	18.0
June	0.01	4.57	0.02	0.09	0.02	0.09	0.59	1.99	69.0	20.9	19.5
July	0.51	5.43	0.02	0.11	0.01	0.11	1.15	1.94	80.0	25.5	18.7
Aug	0.46	5.90	0.03	0.12	0.01	0.12	1.46	2.12	94.0	28.8	19.3
Sept	0.13	6.31	0.03	0.12	0.01	0.12	1.64	2.87	89.0	21.6	18.3
Oct	0.47	6.00	0.01	0.09	0.10	0.18	1.44	1.95	82.5	28.1	21.1
Nov	0.07	6.55	0.01	0.08	0.07	0.15	1.30	2.01	88.5	29.4	20.8
Dec	0.05	5.97	0.01	0.11	0.01	0.14	1.56	2.02	76.6	26.6	17.5
2 April	1.10	0.91	0.01	0.01	0.01	0.03	0.24	1.83	84.0	16.8	0.7
May	0.46	1.07	0.01	0.03	0.01	0.01	0.06	1.81	80.0	18.1	0.6
June	0.95	1.00	0.03	0.02	0.04	0.05	0.13	1.94	87.0	19.4	1.0
July	0.47	0.54	0.03	0.01	0.01	0.02	0.01	1.70	95.0	20.9	0.7
Aug	0.27	0.12	0.02	0.01	0.01	0.01	0.11	1.55	100.0	21.3	1.0
Sept	0.02	0.06	0.04	0.01	0.01	0.01	0.01	3.25	98.0	29.9	1.3
Oct	0.06	0.01	0.01	0.01	0.01	0.01	0.01	2.08	97.2	20.8	1.9
Nov	0.05	0.01	0.01	0.01	0.04	0.01	0.01	1.90	88.9	20.0	1.8
Dec	0.10	0.05	0.01	0.01	0.02	0.01	0.01	1.93	87.2	18.6	1.5

TABLE A-24. LAKE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE VENANGO DEMONSTRATION PROJECT DURING 1982.

Lake No. and Month		Fe	Mn	Cr	Co	Pb	Ni	Al	K	Ca	Mg	Na
		- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	mg/l	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -
1	March	0.18	3.35	0.01	0.05	0.01	0.09	0.70	1.50	53.2	16.2	15.5
	April	0.10	3.11	0.01	0.05	0.04	0.10	0.30	1.63	50.5	15.6	16.4
2	March	1.27	1.79	0.01	0.04	0.01	0.07	0.10	2.01	85.3	19.1	1.3
	April	0.47	1.42	0.01	0.01	0.05	0.06	0.01	2.16	86.4	18.8	1.6

TABLE A-25. ANALYSES OF SOIL SAMPLES COLLECTED ON THE WESTMORELAND DEMONSTRATION PROJECT FOR EXTRACTABLE TRACE METALS THIRTEEN MONTHS (1980) AFTER SLUDGE APPLICATION.

Sludge Application	Soil Depth	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha	cm	µg/g						
0	0-15	7.80	25.10	1.70	4.25	2.35	0.33	3.60
	15-30	2.85	10.65	0.10	1.60	4.25	0.16	3.35
	30-60	3.50	5.20	0.10	0.55	1.65	0.02	2.05
134	0-15	22.07	77.64	5.28	14.39	1.04	0.64	4.74
	15-30	4.42	7.58	0.30	2.08	0.51	0.11	1.95
	30-60	3.98	4.33	0.08	1.03	0.58	0.04	1.80

TABLE A-26. ANALYSES OF SOIL SAMPLES COLLECTED ON THE WESTMORELAND DEMONSTRATION PROJECT FOR EXTRACTABLE TRACE METALS TWENTY-FOUR MONTHS (1981) AFTER SLUDGE APPLICATION.

Sludge Application	Soil Depth	Cu	Zn	Cr	Pb	Co	Cd	Ni
mt/ha	cm	µg/g						
0	0-15	3.60	2.15	0.05	0.25	0.30	<0.01	0.85
	15-30	4.60	3.45	0.05	0.25	0.70	0.01	1.70
	30-60	4.30	3.80	0.05	0.25	0.85	0.01	1.95
	60-90	4.55	5.50	0.15	0.55	1.55	0.01	2.90
134	0-15	43.09	173.45	17.17	23.53	0.93	1.71	9.80
	15-30	6.13	10.90	0.52	2.37	0.67	0.11	2.85
	30-60	4.51	5.93	0.18	1.35	1.89	0.02	2.97
	60-90	4.36	7.35	0.17	1.74	3.49	0.04	3.54

TABLE A-27. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND DEMONSTRATION PROJECT DURING 1980.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - -	- - - - -	- - - - -	mg/l	- - - - -	- - - - -	- - - - -
0	Jan	1.68	41.2	88.8	1.10	154	37.7	1.68
	March	1.28	565.5	44.8	0.75	51	14.7	1.07
	April	1.30	22.2	26.1	2.30	61	12.1	0.66
	May	2.92	50.3	63.3	2.90	147	38.2	1.63
	June	3.04	27.8	44.3	0.69	75	21.0	1.46
	July	2.11	6.3	44.7	0.74	70	21.5	1.92
	Aug	2.29	32.7	44.5	0.72	71	20.5	2.05
	Sept	2.64	9.0	51.7	0.72	91	29.0	2.23
	Oct	1.66	43.8	60.9	0.97	88	26.0	2.69
134	Jan	31.15	50.9	62.4	3.47	198	164.3	4.63
	March	0.61	23.0	22.0	1.93	66	19.3	2.22
	April	1.09	25.7	21.2	4.09	102	21.7	2.33
	May	2.02	30.6	23.0	2.88	119	26.6	2.97
	June	2.34	20.8	15.1	7.53	67	22.0	4.63
	July	5.28	12.2	15.5	1.70	58	21.0	5.36
	Aug	5.10	22.5	14.5	1.96	58	19.0	4.65
	Sept	7.08	12.2	19.1	1.41	54	19.3	3.15
	Oct	5.78	26.9	18.4	1.96	62	21.2	4.07

TABLE A-28. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND DEMONSTRATION PROJECT DURING 1981.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - - - - - - - - - mg/l - - - - - - - - - - - -						
0	March	2.13	53.4	72.7	0.88	105	41.6	1.53
	April	1.41	31.5	50.3	0.84	56	28.1	1.17
	May	2.32	63.8	96.2	1.11	170	32.6	1.71
	June	1.58	9.2	45.8	1.13	102	29.3	2.04
	July	1.77	8.9	29.8	1.31	64	23.4	2.22
	Aug	0.54	8.8	17.9	1.43	156	10.4	2.55
	Sept	1.58	35.3	53.2	1.51	61	29.4	2.41
	Oct	1.57	28.6	52.1	1.39	110	38.0	3.69
	Nov	2.08	6.6	78.6	1.30	187	59.1	3.06
	Dec	1.11	44.0	70.2	1.00	116	40.1	2.38
134	Feb	0.40	26.2	28.2	2.49	98.5	27.9	3.24
	March	0.33	20.1	18.5	2.19	75.3	23.2	2.34
	April	0.31	16.4	13.4	2.08	54.8	17.3	1.70
	May	0.34	16.3	15.9	2.37	53.5	17.4	1.97
	June	0.71	6.9	11.1	2.46	52.1	16.3	1.84
	July	1.15	7.2	9.1	3.19	89.6	33.6	2.30
	Aug	1.12	15.0	10.2	2.92	71.8	18.0	2.43
	Sept	0.81	15.5	10.5	3.96	69.3	19.2	2.35
	Oct	0.60	14.9	13.6	3.21	70.5	22.7	3.22
	Nov	0.58	7.5	15.5	2.27	63.4	23.4	2.00
	Dec	0.33	18.3	17.1	2.68	80.3	26.9	2.31

TABLE A-29. SOIL PERCOLATE ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND DEMONSTRATION PROJECT DURING 1982.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - - - - - - - -	- - -	- - -	mg/l	- - -	- - -	- - -
0	Jan	1.08	43.2	67.7	0.92	115	40.8	2.15
	March	0.96	57.3	97.6	0.98	167	49.1	2.22
	April	0.99	51.6	75.6	0.98	159	41.9	2.28
134	Jan	0.30	19.6	22.7	2.40	77	26.4	2.29
	March	0.24	18.4	21.4	2.48	76	22.9	2.12
	April	0.19	17.7	20.9	2.33	70	21.1	2.40

TABLE A-30. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND DEMONSTRATION PROJECT DURING 1980.

Well No.	Month	Fe	Mn	Al	K	Ca	Mg	Na
		- - - - - - - - - - - - mg/l - - - - - - - - - - - -						
1	Jan	0.57	0.32	0.90	116.0	5170	1.65	29.1
	Feb	0.17	0.02	0.01	65.1	305	1.34	13.0
	March	0.08	0.08	0.07	31.0	321	2.58	1.0
	April	0.39	0.04	0.10	86.5	470	2.51	30.7
	May	0.33	0.08	0.20	88.0	439	4.53	3.2
	June	0.33	0.08	0.10	53.4	470	7.00	33.8
	July	0.38	0.11	0.10	32.6	440	9.00	20.0
	Aug	0.43	0.21	0.10	31.7	500	8.00	20.8
	Sept	0.36	0.24	0.01	48.0	249	6.00	33.0
	Oct	0.14	0.16	0.01	36.8	297	7.00	23.4
2	Jan	31.6	1.86	0.15	5.76	363	79.0	16.0
	Feb	34.8	2.08	0.01	6.00	344	73.3	10.0
	March	31.1	2.18	0.23	5.77	252	64.0	13.4

TABLE A-31. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND DEMONSTRATION PROJECT DURING 1981.

Well No.	Month	Fe	Mn	Al	K	Ca	Mg	Na
		mg/1						
1	Feb	21.3	3.94	0.07	25.8	520	69.3	21.4
	March	61.2	5.23	0.01	14.3	450	75.8	18.7
	April	111.0	6.25	0.04	6.9	420	85.2	18.2
	May	95.3	6.07	0.01	7.2	190	84.1	18.0
	June	146.0	5.24	0.07	4.2	430	84.1	13.6
	July	99.0	5.23	0.05	6.3	77	19.9	18.4
	Aug	86.0	5.72	0.12	4.1	360	80.1	18.6
	Sept	2.6	5.35	0.16	6.4	--	86.2	17.5
	Oct	1.2	5.45	0.38	6.7	368	82.9	19.3
	Nov	2.2	5.20	0.26	6.2	358	82.8	19.0
	Dec	1.1	4.99	0.18	5.5	362	82.8	16.7

TABLE A-32. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE WESTMORELAND DEMONSTRATION PROJECT DURING 1982.

Well No.	Month	Fe	Mn	Al	K	Ca	Mg	Na
		mg/1						
	Jan	7.36	7.77	2.84	6.17	357	86.5	17.7
	Feb	2.76	6.50	0.39	6.82	379	89.6	19.9
	March	2.53	5.70	0.29	5.72	373	83.9	18.3
	April	2.06	4.76	0.10	5.27	12	82.8	19.0

TABLE A-33. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA DEMONSTRATION PROJECT DURING 1980.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - - - - - - - - - mg/l - - - - - - - - - - - - -						
0	Jan	0.03	0.79	6.57	1.62	21.7	8.01	1.00
	March	0.04	0.57	3.19	0.97	7.3	2.72	0.95
	April	0.06	0.80	4.01	1.82	22.4	3.24	0.94
	May	0.15	0.86	4.53	1.46	12.6	5.90	1.34
	July	0.39	0.18	6.25	1.06	3.5	1.00	2.20
	Nov	0.55	2.00	17.60	3.03	68.2	19.65	6.11
80	Jan	0.03	1.08	6.63	0.86	44.2	10.29	0.83
	March	0.06	0.59	3.06	2.38	15.6	3.51	1.21
	April	0.07	0.96	3.57	1.71	58.2	6.55	0.96
	May	0.09	0.90	2.88	2.25	49.9	9.89	1.18
	July	0.03	0.58	3.67	0.88	13.3	5.00	1.22
	Aug	0.46	2.42	21.80	1.46	20.0	8.00	2.93
	Nov	0.36	1.66	22.51	2.52	80.5	38.80	3.52
108	Jan	0.05	2.05	8.98	0.86	186.0	34.41	1.70
	March	0.05	3.36	14.53	0.99	129.2	29.60	2.22
	April	0.09	2.09	5.84	2.18	162.6	15.86	1.93
	May	0.13	1.98		2.96	170.3	26.95	2.35
	July	0.01	0.27	3.05	1.04	12.5	6.50	0.97
	Aug	0.04	0.36	4.20	0.72	7.0	3.00	0.90
	Nov	0.06	0.82	10.92	3.94	124.8	24.15	3.58

TABLE A-34. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA DEMONSTRATION PROJECT DURING 1981.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - - - -	- - - - - - -	- - - - - - -	mg/l	- - - - - - -	- - - - - - -	- - - - - - -
0	March	0.06	0.57	4.94	1.18	21.6	4.85	1.25
	April	0.09	0.85	8.94	1.54	26.3	10.05	1.49
	May	0.14	0.59	4.13	1.53	23.6	7.00	1.65
	June	0.08	0.80	7.11	1.78	26.6	9.95	2.19
	July	0.13	0.92	8.19	2.16	32.1	10.20	3.87
	Sept	0.63	1.65	22.40	4.12	30.5	17.70	4.17
	Oct	0.28	2.13	20.93	2.65	47.7	23.83	5.69
	Nov	0.14	1.39	15.00	2.03	29.4	14.45	3.51
	Dec	0.07	1.27	12.90	1.75	27.2	6.13	2.58
80	March	0.43	0.43	3.15	1.03	36.1	9.17	0.60
	April	0.43	0.80	4.15	1.44	37.0	7.27	0.76
	May	0.05	0.44	1.63	1.21	29.1	5.80	0.56
	June	0.02	0.52	2.07	1.02	33.3	5.48	0.71
	July	0.03	0.61	3.14	1.54	34.7	6.63	1.25
	Sept	0.22	2.79	20.8	3.66	39.0	18.60	1.86
	Oct	0.09	1.77	9.95	2.26	53.0	15.05	2.86
	Nov	5.58	1.13	9.79	1.59	47.0	12.05	4.16
	Dec	24.60	1.14	9.38	1.57	47.1	17.68	4.23
108	March	0.05	0.85	3.28	1.36	126.1	16.73	1.56
	April	0.07	0.78	3.14	1.63	130.7	19.73	1.35
	May	0.03	0.43	2.80	1.77	40.5	14.27	0.93
	June	0.01	0.56	2.11	1.44	101.5	16.97	1.52
	July	0.01	0.49	2.10	1.62	108.1	19.63	2.04
	Aug	0.15	0.26	1.85	1.60	19.5	4.80	0.81
	Sept	0.01	1.03	2.86	1.01	164.8	20.50	2.83
	Oct	0.09	0.79	7.75	3.68	73.3	31.64	4.04
	Nov	0.02	0.65	4.36	1.53	108.1	28.87	2.23
	Dec	0.02	0.65	4.28	1.46	112.3	29.73	2.08

TABLE A-35. SOIL PERCOLATE WATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA DEMONSTRATION PROJECT DURING 1982.

Sludge Application	Month	Fe	Mn	Al	K	Ca	Mg	Na
mt/ha		- - - - - - - - - - - -			mg/l	- - - - - - - - - - - -		
0	Jan	0.04	1.03	7.42	1.06	23.9	4.56	1.81
	March	0.01	0.11	4.50	1.11	3.7	1.40	1.20
	April	0.04	0.42	4.80	1.30	9.9	5.24	1.54
80	Jan	0.46	1.15	6.14	1.38	57.4	21.94	1.26
	March	0.01	0.69	3.63	0.82	35.5	9.80	0.98
	April	0.13	0.64	2.50	0.91	30.6	7.65	1.23
108	Jan	0.02	0.47	2.01	0.85	59.2	17.63	1.43
	March	0.01	0.77	3.33	0.83	110.7	23.62	1.83
	April	0.01	0.51	4.27	1.41	85.6	21.46	1.91

TABLE A-36. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA DEMONSTRATION PROJECT DURING 1980.

Well No.	Month	Fe	Mn	Al	K	Ca	Mg	Na
		- - -	- - -	- - -	mg/l	- - -	- - -	- - -
2	Jan	13.60	2.22	0.20	1.85	22.7	8.69	5.80
	March	3.69	1.45	0.10	1.73	16.2	6.77	6.00
	April	8.31	0.78	0.37	4.75	55.2	6.07	11.24
	May	12.00	1.53	1.00	30.50	77.8	13.60	12.30
	July	2.07	0.54	0.01	0.91	5.0	3.00	10.50
	Aug	1.62	0.51	0.10	0.88	10.0	5.00	9.89
	Sept	1.36	0.79	0.10	0.72	10.0	5.00	9.69
	Nov	0.15	0.80	0.06	1.98	22.3	8.76	14.13

TABLE A-37. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA DEMONSTRATION PROJECT DURING 1981.

Well No.	Month	Fe	Mn	Al	K	Ca	Mg	Na
		- - -	- - -	- - -	mg/l	- - -	- - -	- - -
2	March	3.34	0.42	0.03	2.40	34.4	5.20	10.2
	April	6.20	0.71	0.02	2.03	25.8	4.70	10.8
	May	2.65	0.42	0.01	2.40	21.2	6.30	10.2
	June	3.72	0.35	0.18	2.04	25.3	4.80	10.5
	July	1.75	0.34	0.29	2.20	34.2	6.50	11.4
	Aug	0.92	0.43	0.19	1.55	20.0	5.70	11.0
	Sept	3.04	0.34	0.22	1.72	20.5	6.00	11.0
	Oct	2.15	0.28	0.02	1.74	20.1	7.14	13.2
	Nov	0.38	0.22	0.01	1.65	19.1	7.00	11.2
	Dec	1.98	0.18	0.01	1.65	18.5	8.11	11.6

TABLE A-38. GROUNDWATER ANALYSES FOR SELECTED CHEMICAL CONSTITUENTS AT THE LACKAWANNA DEMONSTRATION PROJECT DURING 1982.

Well No.	Month	Fe	Mn	Al	K	Ca	Mg	Na
		- - - - - - - - - - - -			mg/l		- - - - - - - - - - - - - -	
2	Jan	3.28	0.20	0.01	1.82	21.9	9.04	12.2
	Feb	0.72	0.16	0.02	1.83	21.3	7.00	10.7
	March	0.78	0.15	0.10	1.53	20.2	6.77	10.1
	April	0.98	0.18	0.01	2.11	13.5	4.23	11.2

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